THE APRIL SCIENTIFIC MONTHLY

EDITED BY J. McKEEN CATTELL

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THE SCIENTIFIC MONTHLY

APRIL, 1934

THE CONTRIBUTIONS OF SCIENCE TO INCREASED EMPLOYMENT[1]

A LETTER FROM PRESIDENT ROOSEVELT[2]

The value to civilization of scientific thought and research cannot be questioned. To realize its true worth one has only to recall that human health, industry and culture have reached, in a century of scientific progress, a far higher state than ever before.

The idea that science is responsible for the economic ills which the world has recently experienced can be questioned. It would be more accurate to say that the fruits of current scientific thought and development, properly directed, can help revive industry and the markets for raw materials.

SCIENCE MAKES JOBS

By Dr. KARL T. COMPTON

PRESIDENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY; CHAIRMAN SCIENCE ADVISORY BOARD; CHAIRMAN, AMERICAN INSTITUTE OF PHYSICS

THE idea that science takes away jobs, or in general is at the root of our economic and social ills, is contrary to fact, is based on ignorance or misconception, is vicious in its possible social consequences, and yet has taken an insidious hold on the minds of many people. Conscious of the fallacy of this idea, but characteristically intent on their work and averse to publicity, the productive scientists of the country have thus far taken little or no part in discussions of the subject.

It has become evident, however, that the spread of this idea is threatening to reduce public support of scientific work, and in particular, through certain codes of the N.R.A., to stifle further technical improvements in our manufacturing processes. Either of these results would be nothing short of a national calamity —barring us from an advanced state of knowledge and standard of living and soon placing us at an economic disadvantage in respect to foreign countries

[1] A symposium on "Science Makes More Jobs" presented at a joint meeting of the American Institute of Physics and the New York Electrical Society at the Engineering Auditorium in New York on February 22. The address of Dr. Coolidge was broadcast from Schenectady by the National Broadcasting Company.

[2] A letter addressed to President Karl T. Compton, chairman of the American Institute of Physics, on the occasion of the symposium.

who have not let themselves be swayed by such a short-sighted point of view.

Consequently the New York Electrical Society and the American Institute of Physics are combining in a national service to combat this insidious and dangerous propaganda. They do not, of course, hold that scientific and technical advances have not brought difficulties, like social growing pains. But they strive to prevent us from killing the goose that lays the golden eggs, just because some of these eggs happen to be tarnished. They would advocate careful attention to polishing the eggs and encouraging the goose to lay more of them. In other words, they advocate intelligent and effective attention to remedy each social and economic difficulty as has accompanied the advance of science, and at the same time they advocate the further advancement of science and its applications for human welfare just as vigorously as possible. They do this because the effects of science on human welfare are preponderatingly good and beneficial.

Now we might select any or all of the effects of science on human welfare as the chief point of our discussion to-night. We might, for example, call attention to the effects of medical science. Where would we be to-day without medical science, which has one by one eradicated or brought under control those diseases which used to plague mankind and occasionally to decimate his numbers? Before the days of science these were thought to be the results of the displeasure of gods and demons. Where would we be to-day without the sanitary engineer who safeguards our milk supply and provides a safe and plentiful water supply and disposes of our garbage? In India, where science and engineering have not taken hold, garbage is handled entirely by human hands, by that group who constitute the caste of "untouchables." They are "untouchable" because they carry filth and disease. We might, for example, call attention to modern science in communication and transportation. Would any one like to go back to the days when the only communication was mouth to mouth or by post-horse mail carriage, and the only travel was by foot or horse or crude canoe? Would you like to give up the comforts and conveniences of your modern home, or the thousand and one things which add interest and pleasure and safety to life, which are products of science?

Think for a moment where we would be if our ancestors, alarmed by the progress of science, had taken steps by codes or by public sentiment to stop its progress! You now would be lacking in these things which I have mentioned. And if we, in this day and generation, act to stop science, our descendants will similarly miss the corresponding new advantages which they might otherwise have.

Do not be tempted to think that we are now in a unique position, that these social and economic problems have been suddenly thrust upon us by science, or that science has done what it can for mankind and had better stop. Back in ancient Rome the labor unions were struggling with hours of labor, wages, scab labor just as we are to-day. Back in 1600 Bacon described our present economic and social problems and anticipated some features of the New Deal with remarkable accuracy when he wrote:

> The first remedy or prevention is to remove, by all means possible, that material cause of sedition whereof we speak, which is, want and poverty in the estate (state); to which purpose serveth the opening and well-balancing of trade; the cherishing of manufactures; the banishing of idleness; the repressing of waste and excess by sumptuary laws; the improvement and husbanding of the soil; the regulating of

prices of things vendible; the moderating of taxes and tributes.

Forasmuch as the increase of any estate (state) must be upon the foreigner (for whatsoever is somewhere gotten, is somewhere lost), there be but three things which one nation selleth unto another—the commodity as nature yieldeth it, the manufacture, and the vecture, or carriage; so that, if these three wheels go, wealth will flow as in a spring tide.

And it cometh many times to pass, . . . that "the work and carriage is worth more than the material," and enricheth a state more; as is notably seen in the Low Countrymen who have the best mines above ground in the world.

Above all things, good policy is to be used, that the treasures and monies in a state be not gathered into few hands, for otherwise, a state may have a great stock and yet starve; and money is like much, not good except to be spread.

That great human benefactor, Pasteur, had a grasp of the truth when he wrote: "What really carries us forward is a few scientific discoveries and their applications."

Those in charge of this meeting, however, have chosen not to try to handle the whole field of science and its effects on society but to concentrate primarily upon just one aspect of these social effects, namely, the effect of science upon employment. This is a very live issue in these days of unemployment. It is here that a misunderstanding of the effects of science are likely to be most dangerous, because of possible political influences. Let us therefore consider very briefly what these effects are.

We will immediately admit that technological advances frequently result in labor-saving devices which throw large numbers of men and women out of work. This is distinctly unfortunate. Its evil effects can be mitigated by wise handling of these new devices; as, for example, the American Telephone and Telegraph Company has handled its introduction of automatic switching so as not to throw employees out of work.

But the other side of the picture is immensely more significant in that the major result of science is the creation of entirely new industries which cater to new human desires, and which not only create a multitude of new jobs but which increase the per capita productiveness of men so as, first, to permit of an increasing population which is not limited by starvation and misery and, second, to reduce the hours necessary for men to labor to produce their necessities, and in this way to give them their opportunity to appreciate and experience some of the better opportunities of living which formerly were available only to those of wealth or of politically favored position.

Let me give a few examples of what I mean: Two years ago was celebrated the centennial anniversary of the discovery of the principles of electromagnetism which underlie practically all the modern electrical industry. According to the 1930 census there were in this country about 360,000 persons employed in the manufacture of electrical machinery and equipment, and about 676,334 people employed in the distribution of electrical materials, exclusive of the field of communication, namely, the telephone, telegraph and radio, which contribute in addition an immense number of workers.

Previous to the days of the automobile the 1900 census lists 976,000 individuals employed in the carriage and wagon industry, as manufacturers, drivers, draymen, livery stable managers, blacksmiths, etc. Thirty years later, with the advent of the automobile, based on innumerable scientific discoveries and engineering developments, the census lists 2,409,394 individuals engaged in this industry, exclusive of those involved in oil production. These figures have been corrected to allow for the increase in general population in the same interval. They show that while the advent of the

automobile produced technological unemployment among carriage and harness makers, yet the net result for labor has been a 250 per cent. increase in the number of jobs.

We frequently hear a great deal about the advent of labor-saving machinery on the road which has thrown out of work many men who would otherwise be employed in road construction. An amusing incident in this connection arose a couple of years ago in one of the state legislatures in the discussion of a public works bill for road construction. An amendment was offered to this bill providing that no labor-saving machinery should be used in the construction. The heated discussion of this amendment was brought to a close by the argument of *reductio ad absurdum* when a member of the legislature proposed a second amendment to the effect that laborers should be armed only with teaspoons in order that the number of jobs might still further be increased. What are the actual facts? Again corrected for increase in general population, the twenty years from 1910 to 1930, which witnessed the development of most of this labor-saving machinery, show an increase in the number of employees in road construction and repair from 203,000 to 339,000 individuals.

Such examples might be cited almost indefinitely. I would simply ask the question of where and when our serious unemployment problem should have struck if thirty years ago, to restrain technological unemployment in the carriage and wagon industry, legislation or codes had been enacted which would have inhibited the development of the automobile industry. Such an action would have eliminated the source of income which now supports about 10,000,000 people of our population.

I believe, however, that the argument can be made more fundamental even than this. Man has an irrepressible curiosity for new knowledge. This is the fundamental basis and urge for scientific work. Man has also an irrepressible desire to use his knowledge for the accomplishment of his desires. This is the basis of invention and of engineering. These, I believe, are so fundamentally a part of human psychology that they can not be fettered, though their free exercise may of course be hampered or, on the other hand, be encouraged. The early Egyptians who discovered that a wheel driven by the current or by oxen could lift up water from the Nile for the irrigation of his fields did not worry because this invention relieved him of the job of carrying his water by hand. He simply took advantage of this invention to increase his range of interests and activities in other directions. He cultivated more land, he experimented in early science, he built monuments which he could not have done had he toiled morning to night carrying water by hand. Similarly, I believe that in the last analysis the extent of man's employment is governed by man's inherent desire and urge to do something. If science can relieve him of the more routine tasks, he is free to turn his attention to other things which excite his curiosity or satisfy his desires. In the last analysis, therefore, I believe that science simply increases man's power and the range of his activities. Most certainly, however, both theory and experience prove more conclusively that science has made jobs, not taken them away.

SCIENCE AND INDUSTRY

By Dr. FRANK B. JEWETT

VICE-PRESIDENT OF THE AMERICAN TELEPHONE AND TELEGRAPH COMPANY,
PRESIDENT OF THE BELL TELEPHONE LABORATORIES

I AM a bit embarrassed, because Dr. Compton has upset the cards. I had expected to be at the end of the procession and had assumed, as I think I had a right to assume, that Dr. Compton and Dr. Millikan would cover substantially all the grounds to be covered, and that I would come in at the end to give a few concrete illustrations in support of their theses. But by their having changed the order of the proceedings, I will have to do the best I can. Both Dr. Millikan and Dr. Compton, I think, as you will find, have very carefully prepared their talks. I did not. I assumed I would have a good deal of latitude.

This allegation, that science has shot its bolt and that there should be a holiday on scientific research, of course, is nothing substantially new. Some of us have been hearing this thing for a good many years, but it has reached its crisis in this economic depression. That it is a false assumption, I think is quite easily demonstrable, if one is willing to look at things in somewhat of a broad prospective. And if you look at it this way, you may be able to prove to your own satisfaction that scientific research has increased, rather than decreased, employment.

It has been my lot in life to be a director of industrial research and to see something of its workings—to know about its workings—and to know a bit about the application of science in various industries. Possibly because I am a bit of a philosopher, partly because it is my privilege to be interested in science, and partly because I was asked, some three or four years ago, to deliver a paper at the semi-centennial of the American Bar Association on a review of scientific progress for over fifty years—I began to look into this question of what science had really done—what applied science had done to affect human living.

One of the first things which appears to be of first importance is what has happened in the Western world in the last thirty-five years or so, in comparison to what happened in the rest of the world, relatively. Let us go back to the period of time in the Middle Ages—or later—even up to the end of the eighteenth century. What you find is that goods were produced similarly in all parts of the world and that consequently scientific progress was about the same throughout the world.

Then something happened—at about the beginning of the nineteenth century—in the Western world, which upset existing conditions. That something was the introduction in the western society of science—and the furtherance of the scientific principle in living conditions.

During the nineteenth century, and more importantly, the first part of the twentieth century, that influence has grown and what has been its result is that it is the only major factor which has done more to correlate the markets of the Western world to those of the rest of the world. Consequently, if scientific progress is not the sole cause of whatever has happened to strengthen world relations, it is the major factor in changing existing conditions. During this period of time, the population of the world has increased enormously. More people have been added to the world's population in that short period of time than in any preceding time—and they have been added in the very places

where science has found its work, in the Western world, in America particularly, and in Japan, the only one of the Oriental countries which has applied science.

Now to the question that science has reduced employment. It has greatly increased employment because it has increased the number of people gainfully occupied in its various aspects. Further than that, it has unquestionably increased the pleasure and ease of living in the sphere in which it has been operating. So much for the "look-see" at the situation.

Let's get down now to a little bit more specific proof of what science has done—is capable of doing—is capable of doing in the future. It has assembled the material achievements of the last hundred years and it particularly has assembled the achievements for us in the act of living.

Let us see what progress resulted from the advance in the use of science in industry. At the time of the Centennial Exposition there was no telephone system, no electric light or power industry. There was no automotive industry. There were no aeroplanes—nothing which involved internal combustion engines. There were no chemical industries, which have grown up in the last recent years. There was no motion picture machine, no talking machine, no radio, no picture transmission. We can get up a list of things that are extremely important to-day, which did not exist at all at the time of the fair. Out of these have been built huge industries—the greatest outside of agriculture, which have given employment to untold thousands.

One thing which this exposition did and which they did not expect it to do was that it acted as a great inspiration to the youth of the country, and the result is a vast expansion to the application of science in an enormous number of industries and activities which had not so been benefited before.

Dr. Compton has indicated that in normal times there are one-half million people employed, in the operation of the telephone business in this country. If we subtract what we have learned through scientific research in the last fifteen years, if we go back to the close of the world war, the utility of the telephone as an instrument in our social and economic life would decrease so much as to cut the magnitude of its force to less than half of what it is now. You would have no radio broadcasting, no radio talking pictures—you would have none of these industries which has grown up within recent years and which have given employment to large numbers of people directly employed, or those indirectly employed in these industries which resulted from scientific research and development.

Of my thirty years of industrial research activity, I cannot find a single instance where a scientific achievement has resulted in a reduction in employment. In nearly every case, more work has resulted and there has been a betterment of living conditions. It is true, as Dr. Compton has pointed out, that benefits of scientific research flow to all classes of the population, and even the least competent of the people find themselves a step further from the starvation line.

If one is willing to look at facts in broad perspective, it seems to me that one can not but see that history, in the last 150 years at least, has proven that scientific research, applied to the forces of life, has resulted in better living conditions and an increase of employment for people who are gainfully working in scientific industries. I think that any argument to the contrary is based on complete ignorance, or based on a too-narrow survey of specific, unrelated facts.

THE SERVICE OF SCIENCE

Dr. ROBERT A. MILLIKAN

DIRECTOR, NORMAN BRIDGE LABORATORY OF PHYSICS, CALIFORNIA INSTITUTE OF TECHNOLOGY

My grandad notes the world's worn cogs
And says we're going to the dogs;
His grandad in his house of logs
Swore things were going to the dogs;
His dad amid the Flemish bogs
Groaned ugh! We're going to the dogs;
The cave-man in his queer skin togs
Snarled Gad! We're going to the dogs;
But this is what I'd like to state
Those dogs have had an awful wait.

If any of my auditors to-night doubt that the common man, called above "my grandad," is vastly better off here to-day in depressed America than he has ever been at any other epoch in history, I beg of you to begin to read carefully a bit of that history—or if you haven't time for that, then to make friends with some historian and pump him on the living conditions of the common man in any preceding age as compared with those existing right now in the midst of the world's greatest depression.

If you can not take time to acquire the knowledge which comes from one or the other of these procedures, then all I have to say is you could not take even a bachelor's degree from the California Institute of Technology, for every one of our graduates gets four straight years of English and history in the broad sense of those terms, and that because scientists and engineers who are to be the leaders of the future can not possibly lead wisely unless they have a good deal of familiarity with what man has thought, achieved and *discarded* in the past—also of how his economic and social life has evolved into the present. If that kind of knowledge and background had been the lot of some who have written and talked voluminously during the past five years, the world would have been spared the term "technocracy" and the muddy mess of verbiage which has grown up around it to confuse the public mind.

If you haven't even time for either of the foregoing procedures, then let me ask you at least to take ten minutes to read a brief article by Henry M. Robinson published in the December number of the *Reader's Digest* entitled, "No Time Like the Present." Its simple statement of historic facts will be an eye-opener to some of you.

In suggesting that you read it, I am not trying to lull any one into contentment with things as they are. I am merely trying to start my address with the evidence that enormous progress *has been* made, so that I may be in position to attempt to show how and why it has come about. It is my hope that in this way the muddy stream of public thinking may be somewhat clarified and the road to future progress made more clear.

Let me first quote Mr. Robinson's conclusions from his historic studies. He says, "For all its chafings and imperfections our age is superior in security, comfort, leisure and economic rewards to any other period or condition of life that ever existed in this sweating tear-drenched world." Or again, "In terms of political justice, economic cooperation, health, happiness and human sympathy there has, as yet, been no time like the present."

But I hear my friend Mr. Upton Sinclair and other equally "clear thinkers" of his school saying, "How can Mr. Robinson make ridiculous statements like that about the United States which has developed under a system that has now, as the depression shows, completely broken down?" Of course the answer

to that statement is that there isn't any evidence that the depression shows anything about it; that since depressions galore have happened under all systems we shall have to take a longer look before we can draw any sound conclusions; and when I do that a quite different answer seems to me to stand out with great clearness from the pages of history. For there, one sees great stretches of time in which with many depressions and revivals within them there has yet been on the whole a continuous upward swing. Such a period apparently lasted for thousands of years in Egypt before decay set in. In both Greece and Rome it lasted for hundreds of years before dissolution. In England there seems to have been a rather continuous upward trend for a thousand years and she is going strong yet. And in America we think we have been on the upgrade for 200 years and we are far from being willing to admit that we are yet done.

As I read history, wherever and whenever conditions have been such as to give opportunity to many individuals to develop industry, thrift, self-reliance, resourcefulness and adventurousness—in a single phrase, wherever and whenever the average citizen has been given the opportunity and the stimulus to achievement, there and then you have had an age of Pericles, of Elizabeth, of George Washington, of Victoria, of Theodore Roosevelt. Note, too, that industry and thrift underlie it all, for the adventurer cannot set forth into any unknown land, geographical, commercial or scientific—and it is that kind of adventuring alone that makes for progress—until he has accumulated enough provisions to support him in his expedition. There you have the whole of the theory of so-called capitalism. If I read history aright, any system or set of conditions which furnishes wide opportunity for individual initiative, which inspires many people to thrift and to adventure, makes for progress, while any soft paternalism which kills that spirit makes for decay and retrogression; for a nation is obviously nothing but the composite of the individuals that unite to make it. I have shuddered recently to hear men in high place in American life belittle those old-time virtues of industry and thrift, the discovery of which as fundamental virtues is probably the greatest achievement of the human race to date, transcending in importance all our scientific discoveries put together, for it has underlain them all and made them possible. Once lose that attitude and we are gone!

This doesn't mean that I am arguing for a *laissez-faire* system or that I disapprove regulatory, governmental legislation of the proper kind. In my judgment *laissez-faire* and state socialism have both been historically found to have had the words *mene, mene tekel upharsin* ("thou hast been weighed in the balance and found wanting") written upon their walls, and we must therefore take some intermediate course. I am merely trying to lay down some general principles which, if I have learned the lessons of history aright, must guide that course. Our American public utility system, for example, represents, as I see it, the Anglo-Saxon's genius for finding an intermediate course between two extremes, *laissez-faire* and government ownership and operation of industry, both of which have miserably failed. It has of course been subject to abuses, but I look for their correction and the extension of the underlying principle.

But what has all this to do with science and its applications in the modern world? Everything! For practically the whole of the modern world, governmental and otherwise, is built on science and its applications, and it is the spirit of industry and thrift and adventure that has created modern science.

Just now in the midst of this depression certain voices are raised which counsel us to soft-pedal on science, at least until the rest of the world has caught up. I therefore propose to consider now how much wisdom there is in this counsel.

Before treating it seriously, however, let me first smile with you over the extraordinary adaptability of a depression to the needs or the purposes of every demagogue as well as every sincere but unseeing reformer to exploit his own particular nostrum and also, though sometimes unconsciously, his own self-interest. There are quite as many causes of the depression as there are people who have different axes to grind. Quite oblivious of the fact that the depression has been world-wide and the upswing from it equally world-wide and therefore necessarily essentially independent of our local issues, Democrats and Republicans alike, and some normally intelligent ones, too, blandly charge their opponents with all the ills and take credit to themselves for all the goods. Such is the way of politicians and always will be as long as there is an ignorant and undiscriminating electorate to which they must appeal.

But now leaving behind us childish things, for what is science actually responsible in this American civilization of ours? Let me first give to that question the answers upon which there will and can be no essential disagreement. Science and its applications have so increased the efficiency of labor that here in the United States we produce more of the fundamental food-stuffs, clothing, building materials and fuels than we, just now, know what to do with; and in spite of the present jam in our social machinery which we call the depression the great bulk of all this produce goes now, and always has gone to the common man, that is, to labor. So nearly is that true that any economist will tell you that the standard of living in the different countries of the earth is in general directly proportional to the total productivity of these countries per inhabitant. That is why in spite of the depression the standard of living here has remained relatively high and there has been no appreciable starvation, while in Russia, where the opportunity for, and stimulus to, individual effort has been removed through state paternalism, not less than five million people, according to Whiting Williams, starved to death last year, and also where he says that the well-being of the common man is incomparably lower than it is here when at its worst.

In the second place I need to bring forth no figures to convince anybody that the productivity of labor, brought about by the applications of science in America, has opened up to the common man the opportunities of leisure such as he has never known at any other time or place. When in history has a 40-hour week for the common laborer ever been heard of before? And what glorious vistas of a heretofore undreamed-of-civilization—civilization for the many instead of for the few resting on the backs of the many, as was the case in Athens—can be seen ahead if we can only teach the common man to use that leisure for his self-improvement instead of for his deterioration as he does so often now! This is where our secondary educational system has its greatest opportunity.

About the foregoing contributions of science to our civilization there will be no controversy. But now comes the question upon which the public mind has become much confused because of men who do more talking as I think than they do thinking. These men say "science is responsible for unemployment and therefore for the depression. Science through labor-saving devices is all the time destroying jobs by means of which

men live." The answer to this charge is that it is true, but like most delusions it is only half the truth and therefore fundamentally false. The other half is that every labor-saving device creates in general as many, oftentimes more, jobs than it destroys, and the new jobs are in general better for the individual affected, and much better for society as a whole than the old ones. Labor-saving devices do not in general destroy the jobs that demand intelligence. They cannot do it. The heavy, grinding, routine, deadening jobs are the ones that machinery destroys. In a word, the world's drudgery that used to be done by human slaves is now done by soulless, feelingless iron slaves, and the human is freed for the more interesting jobs of building, running and keeping in order the machines of his creation, or of rendering the public service which the existence of these machines has made necessary. Even if these occupations do not employ all the displaced labor the rest of it ministers to the educational wants that society can now embark upon because of its increased economical well-being.

The progress of civilization consists primarily in the multiplication of human wants. If you want a stagnant civilization you have only to destroy the influences that cause these wants to multiply. The automobile industry has become a largely mechanized one and has destroyed the Studebaker buggy business. It uses still a certain number of operatives with plenty of leisure and good pay to tend its machines—and don't for a minute pity them—but look rather at the hundreds of thousands of good jobs that it has created in garages and service stations. It takes a brain to be a trouble man in a garage—as interesting a job to me as exists on earth—and the service station men! Why, they have improved the manners and the courtesy and the consideration of the American public more than all the colleges in the country put together. We don't call them "professor" yet, but they are doing quite as big an educational job as are most of us professors.

This is but one illustration, but it is typical of the whole process. Taking the long-range view, not the short-range one, I have no hesitation whatever in saying that there is no such thing as technological unemployment. By what authority do I say that? By the authority of the official census of the United States. This lists every decade the percentage of the population "gainfully employed." This was 34 per cent. in 1880 and almost exactly 40 per cent. in 1930—a depression year—and it had shown a steady increase decade by decade, save for a negligible drop from 1920—when war conditions were still on—to 1930. In other words, in this precise period in which science has been applied most rapidly to industry the percentage of our population living by means of jobs has continually increased—comment enough on the soundness of the judgments of those who attribute the depression—which seems to me to be in fact a purely social phenomenon—to technological unemployment.

One more point and I am done. The idea that it might be wise to let the development of the natural sciences wait until the social sciences have caught up is another idea that in my judgment rests upon very muddy thinking. Why? Because it is the change in the conditions of living brought about by developments in the natural sciences that very often makes possible an advance in the social sciences. For example, if we had found no other way of propelling our war ships against the enemy than that which was open to the Greeks and Romans, namely, by chaining human slaves to the oarlocks and lashing them to their task, it may well be doubted whether we should not be doing to-day just this thing that the Romans did 2,000 years ago.

Again, when the cause of yellow fever was discovered by science an enormous social advance became for the first time possible, or when Lauritsen first perfected four years ago a million and a half volt x-ray tube and started with Dr. Seeley Mudd that elaborate and highly scientific research into the effect of such radiation upon deep-seated cancer, the essentially social struggle against one of mankind's greatest scourges entered upon a new phase.

Again, the social scientist looking at war from the historic standpoint declared at Boston last December that hoping for its elimination was as silly as hoping for miracles. He forgot that the developments in the natural sciences are rapidly rendering it inimical to national interests to embark upon an aggressive war. So soon as the jingoes have seen that light or have ruined their nations by shutting their eyes to it, another social miracle will have happened. Once stop the development of the natural sciences, and the chief stimulant to the progress of civilization disappears and the social sciences will begin to stagnate also.

Let me give you just one further illustration that is very near at home for me. The new big Douglas passenger plane has been for long months past in the Daniel Guggenheim aeronautical laboratory at the California Institute, where, according to the official statement of the Douglas Company, 35 miles of cruising speed was added to its performance, 195 miles of cruising speed—15 hours from Los Angeles to New York—(it was actually 13 hours last Monday)—changes more than one aspect of both the transportation and the combat problems. Political manipulation may destroy for a time the social effectiveness of such an advance, but it can not be destroyed for long. Men may come and men may go, human laws may change with the whim of legislators and their supporting public opinion. That is the sad thing about social progress. It may, and often does, go backward instead of forward; but that part of it that rests upon changes in the life of man due to physical discoveries and developments remains immune from political and all other human influences, for its unchanging laws are written in the heart of the universe and progress here is the sure possession of all the ages yet to be. Perhaps the natural sciences are themselves the most enduring and the most effective of the social sciences. Let that thought sink deep into the mind of him who would stay their progress.

SCIENTIFIC DEVELOPMENTS AND THEIR APPLICATION

By Dr. W. D. COOLIDGE
DIRECTOR OF THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

A QUESTION frequently asked by visitors to our laboratory is, What will the future bring? Of course we make no pretense to gifts of prophecy, but the question is not a foolish one, for the closest one can come to an intelligent guess is by studying current scientific developments and their possible applications.

We all know that our present civilization is based on engineering. To realize how completely this is so, we need only to imagine what would happen to any modern city if all products of engineering were suddenly wiped out, leaving the city without electric light and power, with no motors to drive its machines, no pumps for its water supply, no trolley

cars, buses or automobiles for transportation, no telephones for communication, no railroads for bringing in food or for shipping the city's products. That city would survive about as long as a snowball on a hot pavement in July.

So this much we may safely predict about the future. Whatever life may be like fifty or a hundred years from now, we may be sure that the comforts, conveniences, conditions of labor and of recreation—in short, all that determines the standard of living, will depend on the engineering developments that will have occurred in the meantime.

Now engineering is simply applied science. Just as the engineering of today sprang from scientific researches of the past, so the engineering of the future is being shaped by the scientific researches now in progress. That is why the best guess as to the future may be formulated only by a study of recent scientific developments and their possible applications.

There are two things that must strike any student of current scientific progress—the constant acceleration of that progress and the closeness of its approach to the fundamentals of the universe.

In each generation there are those who think that so much has been accomplished that the end of progress is near. I believe it was more than fifty years ago that a commissioner of patents resigned because all worth-while inventions had been made and the Patent Office would soon be useless. It was less than fifty years ago that an eminent physicist said that all the fundamental discoveries had been made, and yet, almost as he said it, a series of discoveries was beginning which has resulted in far greater progress toward an understanding of fundamentals than had been made in all the previous history of man.

It is true that the most obvious things have been discovered, but the army of scientific workers has enormously increased and new weapons of marvelous range and accuracy have been developed for attacking the unknown, so that although the terrain grows more difficult, the forward drive is steadily gaining in momentum. Great as has been the progress of the past fifty years, we may be sure that it will be far surpassed in the next fifty.

The existence of our laboratory has been almost contemporaneous with the development of the newest field of physics—electronics. The electron was first identified by J. J. Thomson in England less than five years before our laboratory was founded. Since then we have taken active part in the development of the present great variety of electron tubes which are already serving man in multitudinous ways. We have the radio tubes which made broadcasting possible, creating a new art which gave employment to tens of thousands and entertainment and instruction to millions; we have the tubes which gave a voice to the motion picture and so increased the range and potentialities of the cinema art; we have the improved x-ray tubes which have so strengthened the hands of the medical profession in its war on disease as to have saved many lives and much human suffering; we have tubes which are producing light more efficiently than our best Mazda lamps; we have the tubes which, in industry, are beginning to take over many control jobs and inspectional jobs, doing them better and quicker than a human operator, and thereby carrying on the work, begun by the electric motor, of relieving labor from drudgery, heightening its efficiency and thereby raising standards of living; and we have the supersensitive tubes which are enabling astronomers to pry into secrets in the far depths of space hidden from the eye and from the photographic plate.

Thus physical research, through its discovery of the electron, has added to human enjoyment, decreased human suf-

fering, raised the standard of living and supplied new and powerful tools for extending scientific knowledge.

The same forty-year period has seen corresponding advances in other fields. Medical research has gone far toward bringing under control such diverse and dire diseases as tuberculosis, diabetes and leprosy. We may confidently expect that in the next forty years such scourges as cancer and pneumonia will lose much of their terror.

So the new discoveries in physics will surely bring, in ways we can not definitely foresee, new and great potentialities to civilization. Those potentialities, properly applied, should bring to all mankind new products, increased efficiency, shorter working hours, more pleasures, comforts and conveniences, better health, all that goes to make life richer and happier. If our economic system is not flexible enough, nor our statesmen and economists wise enough to modify it, so that these potentialities may be realized without unemployment and suffering for many during the inevitable swift transitions, it will be a disaster. But that disaster can no more be blamed on the scientist or his researches than the chemist can be blamed if his discoveries are diverted, by the crimes of political leaders, from their beneficent potentialities in the arts of peace to the wholesale destruction of human life in war.

We should not worry about the advances in natural science. They hold untold benefits for man. Our anxiety should be for the social sciences which are lagging far behind and which only now are beginning to awake to the fact, known to the physical sciences since Galileo's day, three hundred and fifty years ago, that there is only one road to new and certain knowledge—the road that is paved, not by theorizing, but by experiment.

NOTE: The following is an extract from a letter received from Owen D. Young, chairman of the board of the General Electric Company, on the occasion of the symposium: "The notion that science and technical development have resulted in unemployment and financial panic is a characteristic of a depression period. In such periods there is always a search for a devil who caused it. Of all the devils sought in these times of anger and despair, the attack against science is least justified. It not only was not the devil which caused the depression, but it is the most promising angel to lead us out of it.

"If our production were standardized to-day, which so many advocate, and the work distributed among our people, the result would be to focus all of our ingenuity and energy on reducing the cost of the standardized thing. That inevitably would reduce the labor content, and so the work to be divided among our people would surely grow less and less.

"There is no hope in that direction. Replacement would only exist against physical wear-out, and that until now has been only a small part of our replacement program. In America obsolescence—not wear-out—has been the thing which has kept our people at work and at the same time has produced more and better things at less cost for us all to use.

"Science is the mother of obsolescence, and to the extent we paralyze it we will limit employment, wages and our standard of living."

RACING CAPACITY IN THE THOROUGHBRED HORSE

By Dr. HARRY H. LAUGHLIN

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PART II. THE INHERITANCE OF RACING CAPACITY

The Development of a Mathematical Formula by which Nature Transmits Racing Capacity from One Generation of Thoroughbred Horses to the Next

The Thoroughbred or running horse has been bred for more than 300 years by some of the world's most skilled breeders of domestic animals. Substantial resources have been placed at their disposal. The basic aim in this breeding has been to increase the speed of the running horse without sacrificing its ability for sustained effort in distance-going and for weight-carrying. Nothing is more soundly demonstrated in practical breeding than that racing capacity tends strongly to run-in-the-family, and that heredity plays a major rôle in its production. What rules, then, govern its inheritance?

Throughout the present researches much consideration has been given to past investigations of the breeding of the Thoroughbred horse, particularly whenever such studies touch on the inheritance of racing capacity. These studies have supplied a wealth of material, but too many of them have assumed a theory of some sort at the start, and then proceeded to bolster it up by selected evidence—the method of special pleading but not of scientific investigation. The only points upon which all investigators—biological and mathematical, practical and theoretical—have agreed are that racing capacity is a very complex quality, that it tends strongly to run-in-the-family, and that care and training of an exacting nature are necessary to bring out inborn capacity. Obviously, our present task is to find out more exactly just how this inborn element runs-in-the-family. In this work the order of precedency must be facts first and theory second. Accordingly the present investigation will not begin with any theory. It will first seek only the most accurate mathematical picture which can be found for the behavior of Nature in transmitting racing capacity from one generation to another.

Finally, in possession of an accurate yard-stick for the measure of racing capacity in the individual horse we are ready to examine the basic genetic problem: "Given a stallion and a mare, and a group of their nearest blood-kin, each with a definite racing record—each record in terms of sex, age, weight-carried, distance-run, track condition, trueness of the running, and speed—what sort of racing capacities will their offspring possess?" That is, "What is the probability that a pre-selected one of their foals will possess a racing capacity within definitely pre-selected limits?"

Nature of Racing Capacity and the Mendelian Try-Out

Racing capacity in the running horse involves nearly every natural resource of the animal. It is a complex function which calls on physiological and nervous quality, together with the entire ana-

tomical structure of the individual. It is thus, as nearly as almost any quality of which we can conceive, a function of the organism as a whole. Consequently, because it depends upon the whole organism, it is in the horse the result of the somatic development of the thirty pairs of chromosomes, each doubtless with many hundreds of genes. Then racing capacity, far from being a "thing present or absent," or based upon a single gene, is, in its hereditary aspect, more probably based upon the developmental interaction of many thousands of genes.

Practical breeding has contributed substantially to determining the essential genetic nature of racing capacity. The rules by which Nature governs the inheritance of this very definite functional entity in the Thoroughbred horse are not the rules which govern the segregation and the additive recombination of a few genes in the manner followed when the Mendelian formula is applicable. In Mendelian genetics a definite somatic trait—functional or anatomical—is the recognizable developmental product of one or more definite genes in the chromosome. These genes are present in certain alternative combinations. Each such combination results in a definite somatic phase. These facts, together with the supporting discovery by the cytologist about the mechanical behavior of chromosomes and chromomeres, have constituted the principal foundation stones of modern genetics. Random segregations and recombinations of chromosomes in "building the gametes for fertilization," and the facts of fertilization itself, give the mechanical basis for predicting the mathematical probability that the offspring will possess a particular set of somatic traits. Thus Mendelian prediction is always based upon the distribution of the subject-trait among the antecedent near-kin, plus the idealized picture of the behavior of the gene and its chromosome.

But, while this is a most fundamental principle of modern genetics, it is not possible in genetic analysis to apply it to most of the qualities which are useful in actual plant and animal breeding. Nor is the coördination of genetics with embryology, with eugenics or with evolution often possible when genetics offers only the "tools of gross chromosome behavior."

As earlier stated, Mendelian genetics has correlated its phenomena so closely with sound cytological explanation, that good procedure in the genetic study of any specific quality, whether structural or functional, requires that the Mendelian formula be tried out, and that the cytology of the matter be gone into. Accordingly these researches many times examined carefully the possibility of interpreting the observed phenomena in terms of the Mendelian formula.

As a preliminary research the services of Dr. Theophilus S. Painter were secured to make a careful study of the chromosomes of the Thoroughbred horse. He found the haploid chromosome number to be 30, and the usual mammalian x-y sex-type. This was a definite contribution to the cytology of mammalian genetics, but it contributed nothing directly to our ability to predict racing capacity in offspring.

Most studies in heredity look to the development of a prediction-formula. The present researches on the Thoroughbred horse are no exception. We must then compose the correct mathematical picture of how Nature behaves in transmitting racing capacity from one generation to another. If we could tie-up such a prediction-formula with the mechanism of heredity, as shown by the cytologist in his microscopic study of germ-cells and chromosomes, the study would be all the more satisfactory. But whether we can do this or not, we must first have a correct mathematical picture of "how it is" before we can seek hopefully to find out "why it is."

A structural quality like stature in

$$P_{\mathrm{sel.BH}\pm 2.5} = \left[\begin{array}{l} 1.5 \text{ when } \dfrac{21.47\,(BH-2.5)}{.1386\,FI+4.899563} < 113.1199 \\ \text{or} \\ .5 \text{ when } \dfrac{21.47\,(BH-2.5)}{.1386\,FI+4.899563} > 113.1199 \end{array}\right] \cdot \left[\text{Pl. for} \left(\begin{array}{ll} \dfrac{113.1199 \sim \dfrac{21.47\,(BH-2.5)}{.1386\,FI+4.899563}}{24.0814} & \text{when first term of numerator} > \text{second} \\ \text{or} & \\ \dfrac{113.1199 \sim \dfrac{21.47\,(BH-2.5)}{.1386\,FI+4.899563}}{8.5834} & \text{when first term of numerator} < \text{second} \end{array} \right) \right]$$

$$\left[\begin{array}{l} \sim \text{ when both } \dfrac{21.47\,(BH-2.5)}{.1386\,FI+4.899563} \text{ and } \dfrac{21.47\,(BH+2.5)}{.1386\,FI+4.899563} \text{ are } < (\text{or} >)\ 113.1199 \\ \text{or} + \text{ when } \dfrac{21.47\,(BH-2.5)}{.1386\,FI+4.899563} < 113.1199 \text{ and } \dfrac{21.47\,(BH+2.5)}{.1386\,FI+4.899563} > 113.1199 \end{array}\right]$$

$$\left[\begin{array}{l} 1.5 \text{ when } \dfrac{21.47\,(BH+2.5)}{.1386\,FI+4.899563} < 113.1199 \\ \text{or} \\ .5 \text{ when } \dfrac{21.47\,(BH+2.5)}{.1386\,FI+4.899563} > 113.1199 \end{array}\right] \cdot \left[\text{Pl. for} \left(\begin{array}{ll} \dfrac{113.1199 \sim \dfrac{21.47\,(BH+2.5)}{.1386\,FI+4.899563}}{24.0814} & \text{when first term of numerator} > \text{second} \\ \text{or} & \\ \dfrac{113.1199 \sim \dfrac{21.47\,(BH+2.5)}{.1386\,FI+4.899563}}{8.5834} & \text{when first term of numerator} < \text{second} \end{array} \right) \right]$$

FIG. 4. THE FORMULA. OPERATIVE FORMULA FOR THE INHERITANCE OF RACING CAPACITY IN THE THOROUGHBRED HORSE

man, or a functional quality like racing capacity in the Thoroughbred horse, far from being based upon a single or a few Mendelian genes, is, as we have seen, doubtless the developmental end-product of a great many—possibly a thousand or more—genes. In the course of development these genes interact, some accelerating their fellows, others cancelling what otherwise would be high plus-effects in the individual. The resultant is that, keeping environment constant, the pre-selected individual offspring will possess the particular quality in an end-value somewhere on a scale ranging from very low to very high. Although such a quality may be definitely measurable, its constituent nature is vastly too complex to be attributable, in Mendelian fashion, to the additive combination of a few genes. Geneticists can not yet dissect a single complex quality, much less any whole animal organism, into its constituent Mendelian genes. In such a dissection each gene would have to stand for a definite part played in the development of a quality—good or bad, structural or functional—of some sort. Doubtless, with a very few exceptions, each quality of use in practical breeding is based upon many genes, and each such gene, in turn, contributes, in some manner, to a great many—possibly hundreds—measurable structures and functions.

Attempts to throw critically judged, and later accurately measured, racing capacities into classes, and to postulate one, two or three Mendelian units as the genetic basis for variation in transmitted racing capacity failed to give any consistent interpretation. It was necessary to strike out anew.

Formula for the Inheritance of Racing Capacity in the Thoroughbred Horse

Poetically a horse "has racing capacity or he has it not." But, in fact, racing capacity ranges continuously in different horses from B.H. = 0 to B.H. = 140—the latter just a trifle above Man o'War's rating. Granted that racing capacity in the individual horse depends upon the working out of a vast group of genes in the course of development, and that the quality of racing capacity is highly hereditary, the formula for the inheritance of racing capacity must read: "The Probability that the pre-indicated or random-selected foal of a particular sire and dam will develop a racing capacity within definitely named

FIG. 5. MATHEMATICAL MODEL OF THE FORMULA OF THE INHERITANCE OF RACING CAPACITY IN THE OFFSPRING OF THE 54 MARES OF THE MEREWORTH STUD. 1925–1930

The formula for the inheritance of racing capacity in the Thoroughbred horse gives the mathematical procedure to be followed in computing the distribution of offspring into capacity-range-categories. The basis of prediction is called the Futurity Index. It is made up by stressing appropriately a number of the nearest antecedent blood-kin. With a given Futurity Index, or hereditary promise, the formula for the inheritance of racing capacity enables us to compute the probability that the foal with a given Futurity Index will fall within the selected racing-capacity-range. The formula is based upon how Nature has behaved in transmitting racing capacity from parent to offspring—"on experience."

Practically, the problem can be solved for any given Futurity Index by substituting the value of such Index and the value of the selected class-range in the formula and solving for P, or probability. The formula is rather long and descriptive but when reduced to definite FI values it is handled quite readily.

Graphically the same values found in the formula can be picked off of the surface of the above pictured mathematical model. We set the indicators at the selected Futurity Index and at the selected B.H. of offspring, then find the height at which the two pointers meet on the surface, then swing one of the pointers to the "probability post" where one can read off graphically the same values of P which one could find by solving the formula mathematically.

The summation of all probabilities one class-range apart for any given prediction-basis, or Futurity Index, must always equal one or certainty. That is, the foal of a given mating, if it races, will, by a probability of one, *i.e.*, certainty, possess some sort of racing capacity. This formula enables us to break up certainty into its constituent probabilities by capacity-class-ranges.

limits, as a function of the prediction index." In general terms the formula is

$$P = f\,(PI, OCR)$$

In this P = Probability; PI = Prediction index; and OCR = Offspring-class-range. Thus the task narrows down to "Just what prediction-index, just what offspring-capacity-range, and just what function?"

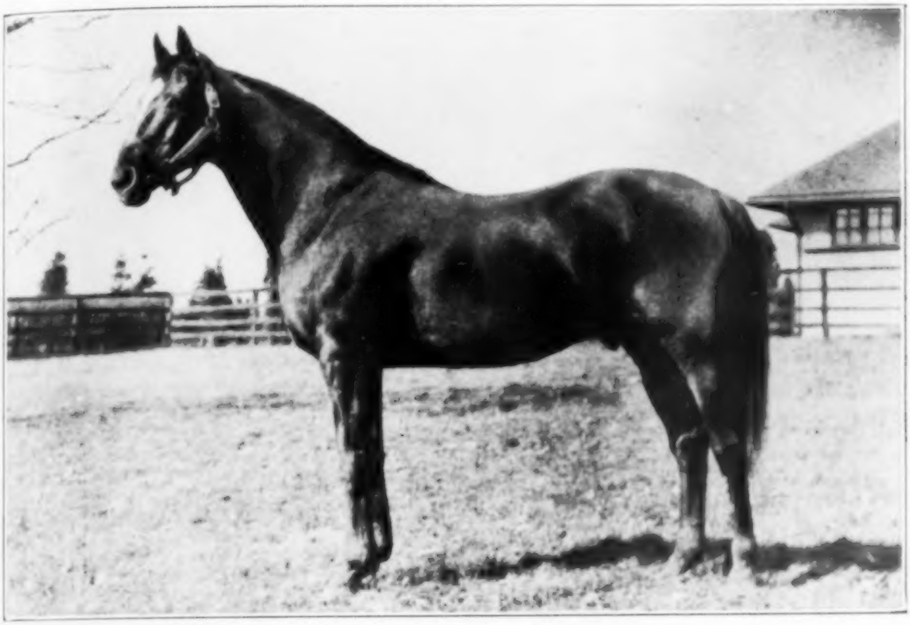
Fig. 4 gives in detail the operative formula for the inheritance of racing capacity; and Fig. 5 shows its mathematical model. This model is so constructed that it may be used for the graphical solution of the formula. One of the three Cartesian coördinates—fore and aft—represents the prediction-basis, another—right and left—the center of the offspring-class-range predicted, and the third—the upright coördinate—represents the probability that, when the selected value of the prediction-basis is used, the offspring will fall into the selected offspring-class-range. Set one of the model-pointers over the selected prediction-basis; set the other over the mid-offspring-class-range "predicted." Then adjust the two arms so their points will meet on the surface of the model. Then swing one arm-point to the vertical coördinate-scale; the point-height thus measures the probability that the selected value of the prediction-basis and the selected offspring-class-range will, in actual breeding, fall together.

The prediction-index is here called the futurity index, or F.I. It is composed entirely of racing capacity values of a group of the nearest blood-kin antecedent to the foal whose racing capacity is predicted. Each near blood-kin constituent of the prediction-basis is stressed or weighted the proper amount, determined by experience to give the most consistent series of predictions.

It must be remembered that the racing capacity of each of these kin is computed from actual race-performances. The real substance of the prediction in heredity, then, goes back for its elements to actual race-performance of the antecedent near blood-kin, with due consideration for sex, age, weight-carried, distance-run and speed attained, other factors being equal. For each individual kin, such a record thus duly computed is its real "past-performance."

Experience has shown that the nearest blood-kin—direct and collateral—constitute a sounder basis of prediction for racing capacity in the foal than can be worked out by tracing descent along a few dilute ancestral lines. That section of the near-kin index of the sire, or of the dam, which goes into the futurity index is called the breeding factor. Thus the breeding factor of the sire, plus the breeding factor of the dam, equals the futurity index of the contemplated foal. The prediction-basis, that is, the futurity index, is the hereditary promise of the foal. Such promise may be computed before the foal is born, or even before his sire and dam are mated. If the contemplated mating does not indicate a desirable hereditary promise, the actual mating need not be made.

In this prediction-basis or futurity index, the breeding factor of the sire is obtained by placing equal stress upon the racing capacity of his sire and of his dam—one sixth each; upon the racing capacity of the sire himself—one third, and upon the racing foals which he has already produced—one third for the group. Similarly the breeding factor of the dam is computed. Equal stress is placed upon the sire and the dam. Such stress-equality is purely empirical. But after many "trials and errors," it was found to constitute a very good prediction-index. A better prediction-index is, of course, possible both theoretically and practically. Studies are now under way, designed to find a theoretically correct stressing for antecedent near-kin in an index of this sort. The practical pur-



FAIR PLAY, CHESTNUT COLT, FOALED 1905, BY HASTINGS, OUT OF FAIRY GOLD

FI—116.68 RC—125.75 NKI—120.71 BF—61.25

FAIR PLAY WAS THE SIRE OF MAN O'WAR AND OF MANY OTHER OUTSTANDING AMERICAN THOROUGHBREDS. BY COMMON CONSENT HE IS RATED AS ONE OF THE GREAT SIRES OF THE BREED.

pose is to find a prediction-index which will make the mathematical model of the formula "very tall, steep, and narrow." For the present all computations of probability of a given racing capacity appearing in the offspring are based upon the Futurity Index, as above stressed.

While the above stresses in the futurity index have been used in the present formula, such stresses need not be the last word. The formula is flexible; with further research we can re-weight or re-stress the several near-kin until a new re-weighting or re-stressing does not produce a better prediction-result. The present unrefined formula is a basic tool or machine supplied with an "adjustment mechanism" for its own perfection; and the test for moving in the direction of truth is better prediction.

The prediction-technique herein worked out is called "ogive-regression-probability." It is so called because in the procedure which found the present operative formula of heredity for racing capacity in the stock sampled, these three principles were used. First the futurity indices were ranged as an ogive, next the mean racing-capacity value of the offspring which each futurity index actually produced was plotted on the same scale. The straight-line fittings for these two series of data—futurity indices and the mean offspring values—show a typical biological regression. Hence the second term in the name of the present technique. The mean-offspring-value line is computed by analytics from the prediction-basis or futurity-index line. The straightened lines of the prediction-basis and of the

MAN O'WAR, CHESTNUT COLT, FOALED 1917, BY FAIR PLAY, OUT OF MAHUBAH

MAN O'WAR IS BY GENERAL CONSENT RATED AS ONE OF THE BEST THOROUGHBRED RACE HORSES WHICH THE BREED HAS EVER PRODUCED. BY THE PRESENT MEASURE OF RACING CAPACITY HE IS CREDITED WITH A BIOLOGICAL RACING CAPACITY OF 139.25.

mean offspring produced need not actually cross at the mid-value of the strains actually sampled; they only point toward a crossing which is the point of no regression for the particular breed-group. If this were the end of the problem, the solution would be relatively simple, but the regression line must be treated as a fluctuation center for offspring values. Here the third term of the name, probability, comes in, for it computes the likelihood that a given offspring will fall within a definite range, the range-center of which is a definite distance from this fluctuation center, measured on the racing capacity scale.

It is noticed in the mathematical model of the formula of heredity for racing capacity (Fig. 5) that the plus values of offspring show a sudden decline in frequency as the higher ranges are attained. This seems a reasonable phenomenon, for in striving to attain the higher levels we should not logically expect as many nor so great successes in the plus direction as we find failures in the minus direction. This expectation is here borne out by the mathematical

picture of how Nature actually behaves when breeders try, by rigorous selection, to improve the breed of the Thoroughbred running horse. This factor gives the skewed shape to the model (Fig. 5).

Overlapping Probability

Practically it happens, and theoretically it is by the present findings expected to happen, that almost any quality of Thoroughbred sire and dam will on occasion produce almost any racing capacity in the offspring. But, depending on the racing capacities of the foal's near-blood-kin, the probability that inborn racing capacity of a certain quality will be possessed by a pre-selected future foal is many times the probability that the same foal will possess a certain other inborn racing capacity. The present study of many Thoroughbred offspring attempts to show just how probable it is that a specific quality of racing capacity will be produced by a given mating.

The overlapping diagram (Fig. 6) is made by "telescoping" two cross-sections of the model (Fig. 5) of the formula, the cross-sections being made at each of two selected prediction-index values. That part of the cross-section probability curve for the greater FI, which is not overlapped by the curve of the lower FI value, shows just how much advantage the given high near-kin have over the given low near-kin in the probability of producing high racing capacity in the offspring. Thus by examining such a diagram, or the statistical tables on which it is based, we can find out how greatly, in the long run, we must improve the near-blood-kin in order to increase by only a little the probability of a slight but definite increase in the racing capacity of the foal. It is noted that each such cross-section moreover, wherever taken on the same model, incloses, with its base, an area of 1.000, which is the probability of certainty. Each offspring must, of necessity, pos-

"GALLANT FOX" AS A FOAL AND HIS DAM "MARGUERITE"

Many breeders consider the sire more important than the dam in producing high racing capacity in the foal, but the present investigations assign credit to racing capacities among the near-kin of the dam at least equal to such credit among near-kin of the sire.

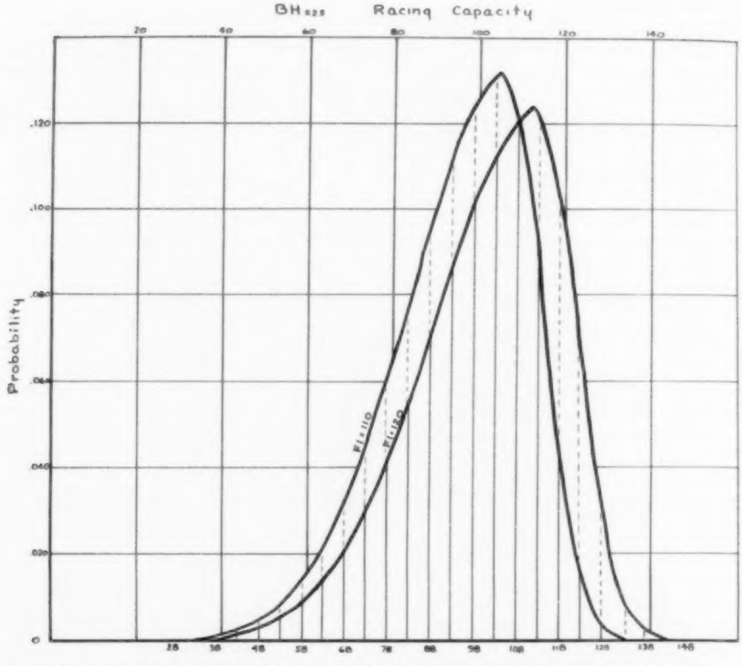


FIG. 6. PROBABILITY "OVERLAP" OF OFFSPRING VALUES

BH EXPECTATIONS FROM FI = 110 AND FI = 120.

Overlap for FI = 110 and 120 areas: $\Sigma P = .8221$ . . . . or $\frac{5}{6}$ overlap
Peak $P = .1205$ at $BH = 108 \pm 2.5$
Limits $P = .001$ at $BH = 38 \pm 2.5$ and 133 ± 2.5

Non-overlap for FI = 110 area alone : $\Sigma P = .1779$ . . . . or $\frac{1}{6}$ non-overlap
Peak $P = .1313$ at $BH = 104 \pm 2.5$

Non-overlap for FI = 120 area alone : $\Sigma P = .1779$ . . . . or $\frac{1}{6}$ non-overlap
Peak $P = .1230$ at $BH = 111 \pm 2.5$

Examples:

1. When $BH = 83 \pm 2.5$
   Overlap. FI = 110–120 $P = .0560$
   In FI = 110 area alone $P = .0222$

   ΣP for $BH = 83 \pm 2.5 = .0782$
   Ratio P's. .72 overlap : .28 FI = 110 area alone or about 3.5 : 1

2. When $BH = 113 \pm 2.5$
   Overlap. FI = 110–120 $P = .0867$
   In FI = 120 area alone $P = .0336$

   ΣP for $BH = 113 \pm 2.5 = .1203$
   Ratio P's. .72 overlap : .28 FI = 120 area alone or about 3.5 : 1

3. When $BH = 133 \pm 2.5$
   Overlap. FI = 110–120 $P = .0005$
   In FI = 120 area alone $P = .0094$

   $\Sigma P = .0099$
   Ratio P's. .05 overlap : 00.95 FI = 120 area alone or 1 : 19

sess a racing capacity somewhere between zero and perfection, and the summation of all of its definite capacity-chances must always equal 1.000.

If, in such a diagram, the overlapping were complete, there would be no such thing as the inheritance of racing capacity; we would get the same range in offspring-values from poor stock as from good stock. In the mathematical model of any specific formula of heredity, steepness and narrowness in general shape, and an axial trend which gives the minimum overlapping, indicate good prediction. If, on the same scales, a model shows much overlapping and a sprawling flatness in shape, it means that the investigator has not succeeded very well in finding a good prediction-basis. But experimental re-stressing of prediction-units can seek a better prediction-basis without destroying the element of truth already found. The present type of operative formula carries procedure for its own criticism and perfection.

Gene-Analysis and Prediction Analysis

If, when we are confronted by a very complex hereditary quality which definitely runs-in-the-family, we use the method here outlined, we can find a mathematical picture of Nature's behavior in transmitting the quality from one generation to another. There is no inconsistency between Mendelian or gene-analysis, on the basis of many interacting factors, and that procedure of genetic analysis which here supplies the specific formula of heredity, by the technique here called "ogive-regression-probability." If with the latter type of analysis the investigator will build the mathematical model for the particular formula, he will be aided substantially

FIG. 6. PROBABILITY OVERLAP

If we take two transverse sections or "very thin slices" from the model shown in Figure 5, and still keep them in their relative positions right-and-left, but push the forward slice backward until it is superimposed on the backward slice, we secure a diagram like Figure 6. The line marked FI = 110 shows probability-distribution by capacity of offspring which come into the world with an FI (Futurity Index, or hereditary promise of a racing capacity) of 110, based on antecedent near-kin racing capacities; while the second bell-shaped curve shows a similar distribution for offspring with a 10-pound higher hereditary promise, namely an FI of 120. The vertical strips within these areas represent ranges of 5 pounds in BH, or racing capacity, of offspring. No matter where we take a cross-section of the model of the formula, the area of the cross-section must always total 1.000—made up of all of its 5-pound probability-strips. If the modal BH class has a low probability, then the cross-section is low and broad—poor prediction; but if the modal class is high, then the cross-section is narrow and tall—good prediction.

If we look at this Probability Overlap chart we find that the best horses produced from mediocre promise are occasionally much better than the poorest horses produced from superior stock, but, in the long run, the better horses come from the better stock. It is the measure of this "long run" which is here worked out.

It is noticed that with FI of 110, the probability of producing a foal with a racing capacity of 118 ± 2.5 is about 4 times in 100, while the probability of producing such a foal from an FI of 120 is about 10 times in 100. If we increase the racing-capacity expectation to 128, the 110 FI shows a probability of about 4 in 1,000, while the 120 FI shows a probability of about 30 in 1,000. It is this "marginal advantage" for which breeders strive in their efforts to secure superior foals and to improve their breeding stocks.

Man o'War is perhaps the greatest Thoroughbred which America has produced. This country is now producing between 4,000 and 5,000 Thoroughbred horses per year, and if it can produce one Man o'War every twenty years it will be doing splendidly. Man o'War was foaled with a Futurity Index or hereditary promise of 113. He actually developed a racing capacity of nearly 140. What is there in heredity if the promise of 113 will produce a capacity of 140 and why did not a higher promise, which sometimes runs as high as 125, produce the best horse?

It is thus seen that the probability of producing a foal as good as Man o'War from an hereditary promise of 113 is about 1 in 8,000. An FI of 113 is itself quite high in hereditary promise, because only a small portion of all foals produced come into the world with an FI of 113 or greater. This is why, if from the present breeding stocks and by the present methods of mating, America can produce a Man o'War every twenty years, she will be doing well.

in the genetic analysis of his problem. For instance, a cross-section of the model in its lower prediction-values (but still, in the present model, substantially above the mean of the breed) will show a tall, steep slope, while another section with a still higher prediction-basis (*i.e.*, still further above the mean) will show a lower, flatter slope. This indicates that heredity-prediction is better among the lower plus-values of racing capacity, for the strain under consideration, than among the upper plus-values.

Again consider the upper breed-values represented by the blood found in the leading breeding farms for the Thoroughbred horse. Among such superior strains, the present evidence indicates that the Thoroughbred horse is less purebred or more variable, in Mendelian terms more heterozygous, for the higher plus- than for the lower plus-values of racing capacity of the antecedent near-kin. As further evidence in using the general formula of heredity as an aid in Mendelian interpretation, we find that, based on the shape of the present mathematical model, the lower plus-values in racing capacity depend upon relatively more recessive phases of the more important constituent genes for this quality than do the higher plus-values. In this, and doubtless in many other ways, the Mendelian interpretation, and the formula of heredity or analysis by ogive-regression-probability, may aid each other. If they are the only two ways of looking at the truth, and each presents a true picture, the two pictures must be consistent.

In the analysis of the more complicated qualities, genetics needs to attack the problem from many directions. It may be interesting, therefore, to compare the uses and limitations of the technique of gene-analysis with analysis by ogive-regression-probability. We find that Mendelian or gene-genetics predicts the nature of the offspring by qualitative classes or categories, determined by one gene or by the additive combination of a few genes. Its principal strength is that it is often able to tie-up its breeding predictions with the underlying chromosome mechanics. Its main weakness is that it can offer no satisfactory genetic analysis or prediction for those more complex traits which are definitely hereditary, and which constitute the main materials with which practical breeders and students of embryology and evolution are constantly working.

Ogive-regression-probability as here outlined presents a general or pattern formula of heredity, the specific application of which also predicts offspring values. The basis of such prediction is a measured or quantitative range-of-value for a single complex trait, rather than for a combination of segregable qualitative or unmeasured traits. For the "thing-predicted" ogive-regression-probability establishes arbitrarily selected but definitely measured offspring class-ranges. It deals with those qualities which result from the developmental interaction of a great many genes. Its main virtue is that, in its attack on genetic analysis, it can produce an accurate offspring-prediction for certain very complex measurable structural or functional entities. Its main weakness is that it can not analyze such traits into their constituent genes; it can indicate only their relative number and potencies. But for the more complex qualities which definitely run-in-the-family neither has gene-analysis made much headway in specific gene-determination. Each within its own sphere, these two types of genetic analysis are equally accurate in offspring-prediction, while each has its own kind of strength and its own kind of weakness. The type of problem, and the "favorableness of the material," determine which technique will probably prove the more profitable. Doubtless in some cases the two methods working together will be more successful in the discovery of the

truth about a genetical problem than either one by itself.

In keeping with current developments in the physical sciences, probability-mathematics comes in for ever increasing usefulness in the biological sciences also. This is true whether the investigator is making an early reconnoissance and seeking a hint of "how it is," or whether the particular study is well developed and he is seeking to defend the theory and to check it critically against experimental facts.

Conclusions

The principal findings of these studies on racing capacity in the Thoroughbred horse are:

1. In order to find the specific formula for the inheritance of the specific quality in a specific group of organisms, two conditions are necessary. First, the investigator must have in hand a reliable yard-stick for measuring quantitatively the particular subject quality; and second, the quality thus measured must show some indication of "running-in-the-family."

2. Racing capacity in the Thoroughbred horse is a definite and measurable functional entity. The existence of long-ago invented yard-sticks for measuring the elements of racing capacity—years for age, pounds for weight-carried, furlongs for distance-run, and seconds for time—made it possible to invent a definite and accurate yard-stick which duly inter-compensates these major factors in relation to speed-attained—other factors, relatively minor, being constant.

3. Nearly every physiological and nervous quality, besides the whole anatomical structure of the individual horse, is called upon for superior racing performance. Consequently the great majority of the individual genes, representing nearly all hereditary resources—in fact the whole organism—is involved in determining the quality of racing capacity.

4. Heredity plays a major rôle in the production of racing capacity, although the influence of care, feeding, training, management and riding are essential environmental factors in the development of ability.

5. The formula for the inheritance of racing capacity in the Thoroughbred horse (Fig. 4) is abbreviated as follows:

$$P \text{ sel. BH} \pm 2.5 = f(\text{FI}, \text{BH}).$$

This means that P is the probability that a potential foal, with a given FI or complex of racing capacities among its antecedent direct and collateral near-kin, will, if such foal races, possess a Racing Capacity within the range BH $\pm$ 2.5.

This is the Pattern Formula of Heredity, a specific case of which is shown in Fig. 4, and the mathematical model of which specific case is pictured in Fig. 5. The fore-and-aft coördinate is the prediction basis, the FI; the right-and-left coördinate, racing capacity, BH, in the offspring by 5-pound ranges; and the up-and-down coördinate is the probability P.

6. With an adequate number of prediction-bases and their corresponding offspring-values in hand, one may apply the pattern formula here developed and thus find an empirical formula by which Nature governs the transmission of the particular quality in the particular group sampled. The present specific formula (Figs. 4 and 5) is for the offspring of the 54 mares produced on Mr. Walter J. Salmon's breeding farm, Mereworth, in the course of these laboratory experiments and which offspring raced to maturity during the years 1925–1930.

7. The prediction-index when it contains only a few ancestors, each doubtfully stressed, gives a low prediction-value; but when it comprises a highly representative group of close antecedent blood-kin, each properly stressed, then the prediction-value of the specific formula is high.

—*Photograph by New Zealand Government*

FELLING A GIANT KAURI (*AGATHIS AUSTRALIS*) AT KAINGAROA, NORTH ISLAND, N. Z.

TWELVE CENTURIES OLD AND STILL GROWING STRONG, SOLID TO THE CENTER, DRIPPING WITH SAP, PITCH OOZING OUT OF THE BARK (ABOVE THE AX), YET THIS MONARCH OF THE FOREST STARTED IN ROMAN TIMES AND HAS SHED A RAINFALL THAT WOULD HAVE COVERED THE EARTH TO A DEPTH OF 10,000 FEET. THE GIRTH IS 66 FEET AND UNIFORM TO THE FIRST LIMB—40 FEET UP, THEREFORE 130,000 FEET OF PINE WITHOUT A KNOT. THE ANNUAL SCALING OF THE BARK ACCOUNTS FOR ITS THINNESS—THE WOOD ITSELF BEING 21 FEET THROUGH. IN SEQUOIA THE BARK IS OVER A FOOT THICK, IN AGATHIS LESS THAN HALF AN INCH, JUST THE YEAR'S GROWTH, TRULY AN OUTSIDE GROWTH, AN EXOGENOUS STEM.

THE NEW ZEALAND FOREST

By V. W. JACKSON

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Of the eight hundred trees, shrubs and vines of New Zealand, six hundred are endemic—not found anywhere else. Why this museum of woody oddities in two islands about the size of the Atlantic states from Georgia to Maine and in the same latitude, 34°–48° south? Isolation is sufficient explanation. Not only is New Zealand separated from the nearest land by 1,300 miles (twice the isolation of Bermuda), but the surrounding ocean is 3,000 fathoms deep, which would indicate long isolation—yes, since early Tertiary times, when the Atlantic states were beneath the ocean and palms grew in Greenland.

No wonder, then, the trees of New Zealand are so peculiar—pines with berries, ferns like trees, broad-leaved evergreens, trees which change their leaves, trees without leaves, trees with daisy flowers, woods that sink in water, woods lighter than cork, Fuchsia-trees, cabbage-trees, net-veined monocots, straight-veined dicots, coniferous dicots; yes, three out of every four you have never seen before, nor anything like them. Of the twenty pines only one has the semblance of a cone and that is as round as an egg. Nineteen pines have gay-colored berries to attract the birds. The berries of the white pine are red at one end and blue at the other, and hence called "soldier berries." Fancy, Verbena trees in flower the year around, but with wood so hard and heavy it sinks, and violet trees thirty feet high, male and female—the Mahoe of the Maori. Stranger still are the daisy trees, the dominant forest trees of Stewart Island, yellow daisy flowers, seeds with thistle-down, twenty different kinds, found only in New Zealand. In fact, of the 1,700 species of flowering plants, 79 per cent. are endemic and half of all the plants are woody, so that the forest flora is the major portion and the keynote to New Zealand scenery.

The New Zealand forest is a true subtropical rain forest, with trees and lianes struggling for a mastery; 182 species of trees, 316 shrubs, 241 semi-woody plants, 51 vines, 12 tree ferns; over 800 woody plants, a tangle of tropical luxuriance, a typical liane: which, like the blessed word "Mesopotamia," brings joy to the rapturous and thrill to the novice—this "rampant wrestle for ascendancy." Clematis and passion-vine, supple-jack and kie entwine the giants of the forest

—*Photograph by J. Martin, Auckland*

THE GIANT KAURI, THE ELEPHANT OF TREES, STANDS IN A CLASS BY ITSELF

A GREEN DORIC COLUMN OFTEN 20 FEET IN DIAMETER AND 60 FEET BEFORE A LIMB, 185,000 FEET OF BEST PINE LUMBER WITHOUT A KNOT. THIS IS THE SOURCE OF KAURI GUM, USED IN FINEST VARNISHES. THE TOP OF THIS GIANT BECOMES THE LODGMENT OF MANY EPIPHYTES, MOSTLY ORCHIDS AND LILIES. THE LONG VINE SEEN HANGING ALONG THE TRUNK HAS GROWN DOWN FROM BIRD-CARRIED SEED OF THIS HARDWOOD RATA AND EVENTUALLY BECOMES ROOTED TO THE EARTH (WHERE THE MAN IS STANDING) AND SOON BECOMES AN INDEPENDENT TREE, STRANGLING LESS STURDY HOSTS, AND BECOMING THE HARDEST AND HEAVIEST OF WOODS.

in their struggle for light and make an impenetrable tangle. The kie-kie is a lily vine, hanging from supporting limbs like a cascade of foliage, and supple-jack is another lily vine, hanging like ropes from the topmost branches and often used as ropes. The Clematis vines, of which there are nine kinds, are all endemic and all dioecious—two kinds, staminate and pistillate; in fact, 46 per cent. of New Zealand flora are unisexual, evidence of primitive types and also of separation for cross fertilization. *Clematis indivisa* forms huge clusters of large white flowers high up in the trees, with the passion-flower hanging lower. To add to the tangle, blackberry bramble was introduced and has so thrived as to become known as bush-lawyer.

In the north island rain forest stalwart pines predominate, with a strange exotic mixture of subtropical palms, cabbage-trees (*Dracaena*) and tree ferns,

—*Photograph by New Zealand Government*

O WOODMAN, SPARE THAT KAURI—THERE ARE FEW LEFT AND NONE OTHERS LIKE THEM

NO OTHER TREE HAS SUCH A MASSIVE, UNIFORM, COLUMNAR TRUNK—WITHOUT LIMBS, WITHOUT A KNOT, THE FINEST LUMBER, THE FAVORITE OF THE CABINETMAKER. NO WONDER IT WAS MUCH SOUGHT AFTER AND NEARLY DISAPPEARED. ONLY ISOLATION IN INACCESSIBLE MOUNTAINS SAVED THE KAURI WHICH ARE LEFT. THE PALMS, TREE FERNS AND GRASS TREES IN THE BACKGROUND INDICATE THE SUBTROPICAL RAIN FOREST.

eight different kinds, in close association with broad-leaved trees with thick, glossy leaves. Monarch of all is the kauri (*Agathis australis*) the most majestic of the pines—great doric columns of stone-gray bark, giving a hazy sanctity to the silent woods. These are the trees primeval—the rearguard of the past, the prophet of the future, fast disappearing before the onslaught of saw and fire; for the kauri is a pine of finest quality, often 16 to 20 feet in diameter, and 80 feet without a knot. It is the "Big Tree" of New Zealand and now must be preserved for posterity as the only pine south of the "Russel Line" with cones and broad leaves.

—Photograph by J. Martin, Auckland

THE KAURI FOREST IS SACRED WITH ANTIQUITIES; GRASS-TREES IN FOREGROUND, CLIMBING FERN ON KAURI TRUNK

TMESIPTERIS, A STRANGE "MISSING LINK" BETWEEN THE SPORE AND SEED PLANTS, EPIPHYTIC UPON THE TRUNKS OF TREE FERNS. THE WIRY VINE TIGHTLY APPRESSED AND ASCENDING THE KAURI TRUNK ON THE RIGHT IS A CLIMBING FERN (*Lygodium*) ENDEMIC TO NEW ZEALAND. THE PALM-LIKE CLUSTERS ON THE LEFT ARE NOT THE LEAVES OF A MONOCOT BUT OF A HARDWOOD DICOT—THE ONLY ONE WITH STRAIGHT-VEINED LEAVES.

—Photograph by New Zealand Government

TROUNSON'S KAURI PARK, NORTH AUCKLAND, N. Z.; ONE OF SEVERAL STATE FORESTS

LIKE THE REDWOOD, THE KAURI HAS A VERY LIMITED RANGE, ONLY THE NORTHERN TIP OF THE NORTH ISLAND, LAT. 33° S. TO 38°. ONLY TOO LATE NATIONAL KAURI PARKS HAVE BEEN SET ASIDE TO PROTECT THIS FAMOUS TREE FROM EXTINCTION. THE STATES FORESTS ACT OF 1922 PROVIDES £1,000,000 FOR PROTECTION AND AFFORESTATION AND THE KAURI STAND IS NOW A STATE MONOPOLY, A NECESSARY PROTECTION AGAINST GUM-POACHING, FOR KAURI GUM IS A VALUABLE BY-PRODUCT.

The other 19 pines have fleshy berries or colored, aril growth around the bony seed like the yew and are therefore Taxaceae and not Pinaceae, certainly not Coniferae—not cone-bearers. The four most common pines, totara, miro, matai and white pine, belong to the genus *Podocarpus*, which means a berry with a

base: the white pine or "soldier berry" being red below and blue at the top, like the French gendarme. The Maoris are fond of these berries. The average tree is 120 feet and the wood is used in making butter boxes and paper. The two black pines, miro and matai, have fruits like a plum; the red miro being the favorite fruit of the native pigeon, and the black plum of the matai is partly hidden among flat leaves on spreading branches like a dicot: you would never guess it a pine until you tasted the pitchy leaves or berries. The totara was the favorite of the Maori, for out of it he carved his war canoes, sometimes 70 feet in length and enduring the centuries, for it is one timber which resists "Teredo," the ship worm.

The hardwoods are not less remarkable. Three of them sink in water and can therefore not be floated to the mill. Even my Maori war clubs, cracked with time and desiccation, sink like lead in water, a real bludgeon these, of black maire (Olea—olive) and rata or ironwood (*Metrosideros*, which means hard as iron). Black maire weighs 72.3 pounds per cubic foot, and growing beside it may be whau, a New Zealand basswood, which weighs only 11.7, the whole log lighter than cork, and used as

—*Photograph by J. Martin, Auckland*

A STRANGE MEDLEY OF MONOCOTS AND DICOTS; THERE ARE 185 SPECIES OF COASTAL FLORA

GROWING UP THROUGH THE NEW ZEALAND FLAX (*Phormium tenax*) IS THE CABBAGE TREE (*Cordyline australis*) LIKE A HOTHOUSE DRACAENA ON A POLE. THE WAVY-LEAVED RANGIORA ON THE RIGHT HAS FLOWERS LIKE AN ASTER, AS HAVE MOST OF THE TREES ON STEWART ISLAND OF THE GENUS SENECIO—DAISY TREES, IN FACT. THE CROOKED BRANCHES OF THE POHUTUKAWA OR CHRISTMAS TREE WITH ITS SCARLET FLOWERS REACHES FAR OUT OVER THE WATER IN SEARCH OF LIGHT.

—*Photograph by J. Martin, Auckland*

PALM, PINE AND FERN HOLDING UP A TANGLE OF VINE; A TYPICAL LIANE RAIN FOREST

KIE-KIE, SUPPLE-JACK AND CLEMATIS ALL ONE ENSEMBLE KNOWN AS RAIN FOREST OR LIANE. THE PINES HAVE BERRIES INSTEAD OF CONES; THE FERNS HAVE TRUNKS LIKE TREES; THE VINES HAVE SHOWY FLOWERS; THE EPIPHYTES ARE WHITE LILIES OR DENDROBIUM ORCHIDS; A KAURI PINE IN MID-BACKGROUND AND A WHITE PINE BEHIND THE NIKAU PALM.

floats in netting whales—one wood over six times as heavy as the other. Interspersed with these hard woods, with thick, glossy, dark-green leaves and prune-like fruits, will be nikau palms and cabbage trees (*Dracaena*), a medley of the tropical with the antipodal, a vegetational vaudeville.

The evergreen broad-leaved trees and freedom from frost means an evergreen forest relieved only by flowering trees, for there is neither room nor light for wild flowers and most of the tree flowers are greenish, but at Christmas time the Christmas tree, pohutukawa (*Metrosideros tomentosa*), bursts scarlet red with bloom—the countryside becoming red over night—a red Christmas instead of a white one.

The southern rain-forest is a beech-forest, an almost pure community of one or more species of beech (*Nothofagus*) in a bed of fern. Even the beech is antipodal, more like birch than beech and called red and black birch by the lumberman. However, they have burry beech-nuts and outstretched horizontal branches—*Nothofagus* if not *Fagus*. But the tree ferns are much the same and the keynote of the New Zealand forest—a continuity and a tropical character, which makes the New Zealand forest one liane or tangle of endemic trees, ferns and vines.

It is most surprising to find these tropic-like tree ferns as far south as the Auckland Islands, Lat. 50° S.—the latitude of Winnipeg and the Aleutian Islands. Humidity and the tempering influences of a vast surrounding ocean make this possible.

Although isolation tends to fixity of species and 79 per cent. of the flora is endemic, yet there is a remarkable and unexpected hybridization—353 species-hybrids and 101 generic-hybrids, mostly among trees and shrubs. Of the sixty coastal trees and shrubs 10 per cent. of them have hybridized—one tree-shrub hybrid. Of the 222 lowland trees and shrubs there are seven tree-hybrids, 25 shrub hybrids and two between trees and shrubs. Of the 125 mountain trees and shrubs there are 47 hybrids, and among the 45 lianes there are 10 hybrids and 9 epiphytic-hybrids, in all 87 hybrid groups among the 410 woody plants, and 107 among the 845 herbaceous. Such hybridity or heteroblasty makes systematic flora a very difficult and puzzling problem. It has challenged the botanists of the world for half a century. Hooker, Travers, Engler, Colenso, Kirk, Petrie and Cheeseman were puzzling over these things in floras of fifty years ago, and more recently Dr. Cockayne and Dr. H. H. Allan have studied this hybridization critically, and find well-established varietal groups, notably Veronicas, Pimeleas, Pittosporums, daisy trees, cabbage-trees, spiderwoods and many others. And all this hybridity with a scarcity of insects and birds! True, most of the flowers are white and these attract moths at night, and the honey flowers of the trees attract the birds, but such surprising hybridization must be due to the equally surprising fact that nearly half the flora is unisexual, that is, the flowers are of two kinds, staminate and pistillate, male and female, on the same or on different trees, and therefore must be crossed, if fertilized at all. It has been estimated that 54 per cent. are thus cross-fertilized, and the possible isolation of such incipient species prevents the swamping effect of crossing, as on continental areas. So we have this unique flora of New Zealand—79 per cent. endemic, 46 per cent. unisexual, monoecious or dioecious, nearly half the flora woody—trees, shrubs and vines, hence a forest of oddities, antipodals, daisy trees, grass trees, fern trees, pines without cones, trees without leaves (*Phyllocladus* and *Carmichelia*), trees with changing leaves (lancewood, Discaria, ribbon wood), the

—*Photograph by J. Martin, Auckland*

PERHAPS THE MOST SOUTHERN TREE-FERN, LAT. 45° S.

WITHIN SIGHT OF THE TASMAN GLACIER, SOUTHERN ALPS, N. Z., LAT. 45° S. (LATITUDE OF MONTREAL), THIS BLACK TREE-FERN (*Cyathea medullaris*) HOLDS ALOFT ITS DELICATE FRONDS, 20 FEET LONG. SLIGHTLY SMALLER TREE-FERNS (*Hemitelia Smithii*) GROW ON STEWART ISLAND, LAT. 47°, AND EVEN ON AUCKLAND ISLAND, 50° S. (LATITUDE OF WINNIPEG AND ALEUTIAN ISLANDS).

—Photograph by New Zealand Government

THE MILFORD TRACK, THROUGH THE SOUTHERN BEECH-FOREST, SOUTH ISLAND, N. Z.

ONE OF THE FINEST WALKS IN THE WORLD, THROUGH FERNS AND BEECH, MILES AND MILES, AND THERE IS NO OTHER WAY THAN WALK THROUGH THIS MOUNTAINOUS REGION TO MILFORD SOUND ON THE WEST COAST. ALTHOUGH IN A SEEMING TROPICAL FERNERY THERE IS A CHILL IN THE AIR FROM THE NEARBY GLACIERS AND THE FIRST OPEN VIEW WILL LIKELY REVEAL THE FRANZ JOSEPH GLACIER ON MT. COOK, 12,349 FEET ALTITUDE—TREE FERNS AND GLACIERS, A FLORAL PARADOX AS WELL AS A FLORAL PARADISE.

thick, glossy, tropical leaves, spiny, xerophytic leaves (where there is 200 inches of rainfall), hardwoods heavy as stone or light as cork—a forest laboratory, trying out everything, keeping that which has stood the test of time, some since Devonian time.

CLASSIFICATION OF NEW ZEALAND WOOD FLORA
(Referred to in text)

Tree-ferns: *Cyatheaceae*
Cyathea dealbata; ponga; silver t.f.
Cyathea medullaris; Koran; black t.f., 50′
Dicksonia squarrosa; weki; 20′
Dicksonia fibrosa; weki-ponga, 20′

Pine, Conifer: *Pinaceae; Araucarieae*
Agathis australis; kauri
Yews; Taxaceae; Podocarpeae
Podocarpus totara; totara (pine)
Podocarpus ferrugineus; miro; black-pine
Podocarpus spicatus; matai; black-pine
Podocarpus dacryroides; kahikatea; white-p.
Dacrydium cupressimum; rimu, red-p.
Phyllocladus trichomanoides; celery-leaved p.

Screw Pine Family: kie-kie vine
Palmaceae; nikau palm, only palm
Liliaceae; cabbage-tree (Cordyline) Dracaena
Supple-jack vine (*Rhipogonum scandens*)
New Zealand flax (*Phormium tenax*)

Beech Family: *Fagaceae*
Red birch; *Nothofagus Menziesii*
Black birch; *Nothofagus fuscus*
White birch; *Nothofagus solandri*

Nettle Family: *Urticaceae*
Nettle-tree; *Paratropbis microphyllus*
Nettle-bush; *Urtica ferox*

Mistletoes: 3 parasitic Loranthus, Viscum, Tupeia
Proteaceae; Australasian only
Rewa-rewa; *Knightia excelsa,* 100′

Sandalwood; *Santalum Cunninghamii*
Polygonaceae; Climbing shrubs (Muhlenbeckia)
Ranunculaceae; Climbing *Clematis indivisa*
Magnoliaceae: pepper tree; *Drimys axillaris*
Lauraceae; tawa and tarairi (*Beilschmiedia*)
Saxifragaceae; seven trees—Weinmannia Carpodetus, Ixerba and Ackama
Pittosporaceae: Matipo; Australasian Pittosporum—17 trees and shrubs
Leguminosae; mostly trees and shrubs, Sophora
Violaceae; Violet-tree, Melicytus; Mahoe
Mahogany: *Dysoxylum spectabile;* kohe kohe
Maple family: *Dodonaea* (ake), Alectryon (Titoke)
Passifloriae; Passion flower vine
Karaka: *Corynocarpus laevigata,* "laurel"

Basswood, Lime or Linden Family
Whau; *Entelea arborescens,* lighter than cork
Himau; *Eleocarpus dentatus,* softwood
Ribbon woods or Mallows
Lacebark: *Hoheria populnea*
Ribbon wood; *Plagranthus betulinus*

Daphne family: a dozen shrubs (*Pimelea*)
Myrtle family: tea-trees and ratas
Leptospermum—3 teatrees, Manuka
Metrosideros, 9 large trees and 2 vines
Myrtus—4 shrubs
Eugenia Maire, hardest of woods
Fuchsia-tree; *Fuchsia excorticata*
Dogwoods; Broadleaf Griselina
Araliads; Lancewoods—13 species Nothopanax 7, Pseudopanax 6
Wintergreen tree; *Gaultheria antipoda*
Grass-trees; *Dracophyllum*—18 species
Olive Family: Olea; maire—heaviest of woods
Verbenaceae: 4 hardwood trees, Vitex Avicennia (Mangrove) and Myoporum
Veronica; 84 species, mostly shrubs
Coprosma; 40 species, mostly shrubs
Compositae; Daisy family, mostly trees and shrubs in N. Z.
Olearia—35 trees and shrubs, all endemic
Senecio—20 trees and shrubs, all endemic.

THE ENTOMOLOGICAL SOCIETY OF LONDON

By Professor T. D. A. COCKERELL

UNIVERSITY OF COLORADO

THE first of all entomological societies appears to have been founded in London in the forties of the eighteenth century. Practically nothing is known about it, except that the members used to meet at the Swan Tavern, 'Change Alley, and that on March 25, 1748, a great fire occurred, which destroyed both library and collections. A meeting was in progress when this happened, and the members had difficulty in escaping with their lives. This disaster seems to have put an end to the society. In 1762 a second Aurelian Society was founded, and for a time seemed to flourish. But before the end of the decade it had come to grief, and on February 28, 1768, the English entomologist, Dru Drury, wrote to Pallas in Russia: "I sincerely lament with you ye fall of ye Aurelian Society, there wanted but two or three good members to have made it become respectable, but Da Costa's temper and principle was sufficient to overturn a kingdom."

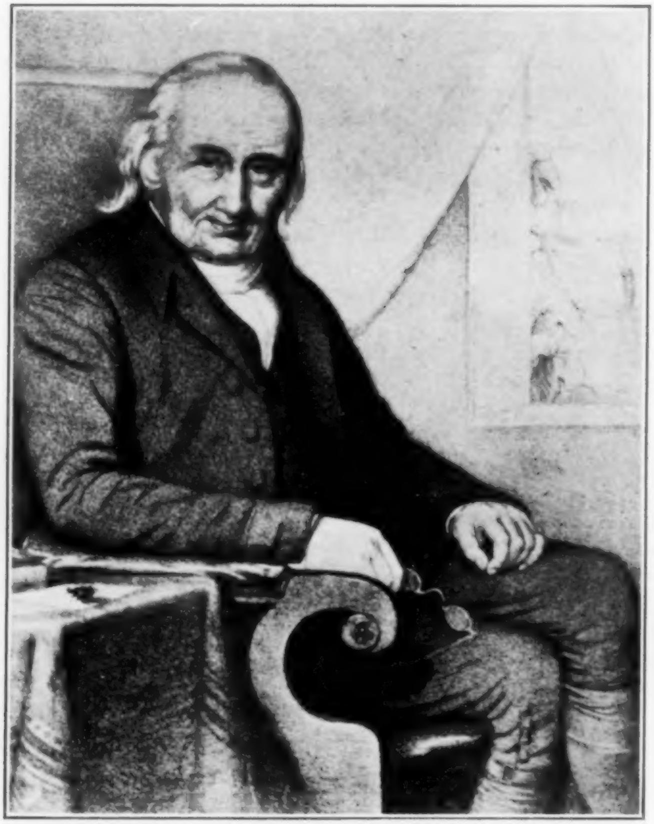
Another society was founded in 1780 and lasted two years. Then in 1801 the name Aurelian Society was revived for a new organization, which dissolved in 1806. From this time on various efforts were made, and the long record of failures seemed to suggest that a society devoted to entomology alone could not have lasting success. The Linnean Society, covering the whole field of biology, was a flourishing institution, and many felt averse to dividing up the field, and creating special societies concerned with portions of it.

All this was long before the rise of economic entomology, and those who studied insects were amateurs, interested in the beauties and wonders of nature. They were not "mere collectors" by any means, but also took a keen interest in observing the habits of their favorites, as is well shown by the letters of Dru Drury and the writings of William Kirby. In spite of so many difficulties and discouragements, they still felt that they must come together to discuss their common interests and that the field of entomology was large enough to justify a special society. Indeed it may be said that the variously abortive efforts of nearly a century past had but paved the way for the success which was to come.

So it came about that on May 3, 1833, a group of men met at the British Museum, and decided to establish the Entomological Society of London, which has steadily developed during the past century, and recently celebrated the hundredth year of its existence. In commemoration of this event the society has just published "The History of the Entomological Society of London, 1833-1933," by Dr. S. A. Neave, assisted by Mr. F. J. Griffin, with an introduction by Professor E. B. Poulton and a financial chapter by A. F. Hemming. It is from this excellent account that I derive most of my information. The society started well, with 107 members in its first year, including Charles Darwin and others already eminent or destined to become so. The venerable William Kirby, rector of Barham, at that time the most distinguished British entomologist, was elected honorary life president. Probably the most influential and in the long run the most distinguished as an

entomologist of all the original members was John Obadiah Westwood, for long years professor at Oxford. He died as recently as 1893, and among my most treasured memories is that of seeing him preside at one of the meetings, when he read a paper on a new kind of plant-louse found on breadfruit in Ceylon. Westwood it was who published the classical "Introduction to the Modern Classification of Insects," which did indeed place the whole subject on a new basis, and marked the beginning of a new era in entomological science. Before the general recognition of the importance of economic entomology, he concerned himself with injurious insects as such, and published many important

41 QUEEN'S GATE, THE HOME OF THE SOCIETY SINCE 1921



REVEREND WILLIAM KIRBY, F.R.S.
HONORARY LIFE PRESIDENT, 1833–1850.

papers in the *Gardener's Chronicle*. He studied all groups of insects, and his enthusiasm never flagged, so that it was said of him that in spirit he never grew old. His artistic powers were great, and led him not only to skilfully illustrate innumerable insects, but also to become a leading authority on medieval manuscripts.

When one looks at the list of men who established the Entomological Society in 1833, the number of first-class men is astonishing. Some of them are chiefly known to-day for their activities in non-entomological fields, such, for instance, as Charles Darwin, Sir J. D. Hooker and W. Yarrell. But I can count about fifteen outstanding entomologists, whose work will never be forgotten. These alone would have given luster to any organization they might have chosen to form.

For the first three decades the membership remained between 150 and 160, but then it began to increase, the subsequent decades (beginning with 1863) showing 194, 223, 289, 404, 522, 622 and 685. This steady progress did not mean unclouded prosperity. The finances were often the occasion of serious anxiety, but large and frequent gifts from certain of the members tided over difficult times, and especially made possible the publication of important illustrated papers.

JOHN OBADIAH WESTWOOD
HONORARY SECRETARY, 1834–1847; PRESIDENT, 1851–1852, 1872–1873, 1876–1877;
HONORARY LIFE PRESIDENT, 1883–1893.

As recently as 1874 it was actually proposed to merge the Entomological Society with the Linnean, and such an arrangement was very nearly made. In the early days of the society, a collection of insects was formed, and this soon came to be of considerable importance. In 1835 the Reverend Wm. Kirby presented the whole of his collections, including the types of bees described in his Monographia Apum Angliae, the basic work for the knowledge of British bees. In 1841 Darwin presented a collection of insects obtained on the voyage of the *Beagle*, "and it appears that on his return from his famous voyage, Darwin was much exercised in his mind as to the disposal of his collections. For some reason he was not anxious to present them to the National Collection at the British Museum, and portions of them were presented to this Society, and, as may be seen from the Centenary History of the Zoological Society of London, others were handed over to that body. As is well known, however, the most valuable portions of both these collections eventually reached the British Museum." To this I can add that I found a couple of bees (one of them still representing a new species) in the Hope Museum at Oxford, collected by Darwin in

Australia and Tasmania. It is unfortunate that the history of many of the specimens of insects collected in the early days, and made the types of newly described species, is now difficult or impossible to trace. At first it was not customary to put locality labels or other data on the pins, and thus it happened that after Dru Drury's collection, with its many types, was sold, no one could say what specimens belonged to it. Very probably some or many of them are still extant, but there is no way to prove it. At the British Museum, it was the custom to put a little label on the pin, showing the year the specimen was received, and the number given to the accession in the accession-book. Thus 50.10 would mean accession number 10, of the year 1850. When these insects were described as new, it was not usual to cite these numbers, but any one who would now go to the museum, and ascertain the numbers on the innumerable types, and look them up in the accession-books, would undoubtedly discover much of interest for the history of entomology. Often, of course, the record merely gives the name of the donor, but frequently the collector or the locality can be ascertained.

As might be supposed, the collection of the Entomological Society eventually reached such a size that it was impossible to take care of it. Adequate room could not be found, and the problem of keeping it properly arranged proved insuperable. In 1858 the exotic insects, except the types of new species, were sold by auction, and in 1863 the society disposed of the last of its collections, the types going to the British Museum. In the thirty years since the foundation of the society, the British Museum had increased its facilities and its staff, and it was to the advantage of all concerned that it should become the custodian of these precious materials.

The library, on the other hand, had a very different history. As it grew in size and importance the problem of housing it and making it available became acute. The story of how the difficulties were overcome is a long one, but to-day it is estimated that the society possesses about 12,000 volumes and 30,000 separates, much used by the members. The question might be raised, why the society should maintain this great library, when that of the British Museum (Natural History) is available just around the corner. But the library of the society can be loaned to members, and is increasingly used in this way. An evil resulting from the growth of modern science is that the student, unless he lives near or is connected with some great institution, or is unusually wealthy, can not obtain the literature for serious original researches. Indeed, even large universities do not possess all the necessary literature, except in restricted fields which have been especially cultivated by members of the faculty. The consequence is that students have to depend for the determination of specimens and various kinds of advice on the staffs of large museums, service which can only be rendered at the cost of time and effort which would better be directed to work of more lasting value. Even when museums or universities are willing to do this work of determination, the results are often unreliable. Every large collection grows by accessions from many sources, and it is utterly impossible for the curators to check up the determinations of the species as they come in. Also, it is very difficult to match species correctly, if one is not familiar with the special specific characters. It is accordingly necessary for the sound progress of entomology that there should be many workers specializing in particular groups, exchanging specimens and opinions, and becoming familiar with all the details of their subjects. Such workers, it is obvious, are likely to be

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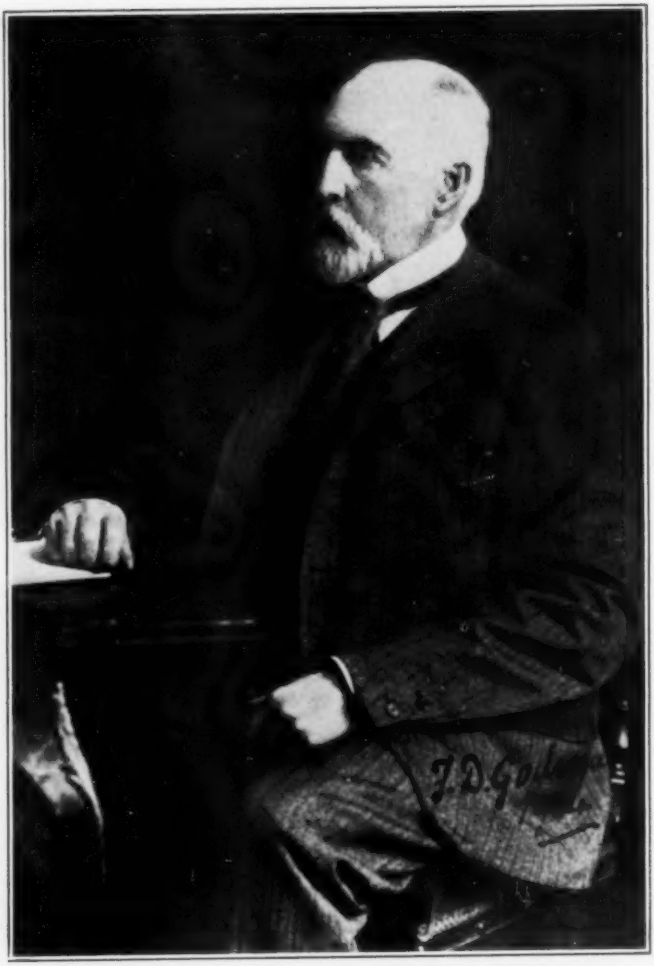
more numerous and more efficient if they can gain access to the most necessary books. One of the greatest possible services to American science would be the establishment of a great loan library, especially of authors' separates, which could be sent out to students under properly safeguarded conditions. The need is partly met by inter-library loans, which are exceedingly helpful, but in the nature of things can not be really adequate.

From the beginning, it was one of the chief concerns of the society to publish its Transactions. There was at first considerable opposition, partly on account of expense and partly because it was feared that there would be serious competition with the *Entomological Magazine*, which had been founded in 1832. Such objections were not allowed to prevail, and it was soon recognized that publication was one of the chief functions of the society. In 1931, to meet the difficulty of publishing short taxonomic papers, the society established the monthly journal *Stylops*, and it is to be noted that the ancient objection, concerning the fear of competition with existing journals, was voiced once more in certain quarters, but with no more effect than before. As a matter of fact publication facilities are still extremely inadequate, and workers are discouraged from attempting comprehensive monographs or long papers.



F. D. GODMAN

In the early fifties, it was proposed to publish a series of volumes under the title *Insecta Britannica*. Volumes on the Diptera (flies) and smaller moths actually appeared, but the scheme was never completed. There were various reasons for this, including disputes as to the arrangement and contents of the volumes. To-day it would be recognized that in order to adequately deal with the British fauna, it is necessary to study that of the whole Palaearctic Region, and preferably also that of North America. To begin with the British insects alone is to begin at the wrong end, though it is useful eventually to publish special accounts of the British fauna, to serve the needs of collectors who do not study exotic species. In the early days, when material from abroad was not so generally available or easily obtained, it was a kind of necessity to mainly confine the work to the local species; but the evils resulting from this practise are evident when one contemplates the immense and complicated synonymy of European insects.

In 1867 the Neuropterist, McLachlan,

proposed that a Catalogue of British Insects should be compiled and published by the society. Some parts of this appeared, but the project was never completed. A serious obstacle was the disagreement concerning the nomenclature to be used, there being two opposing groups within the society. An up-to-date Catalogue of British Insects would to-day be of very great value, and also would be easier to produce, as there are so many more monographic or revisional works on which it could be based.

When we consider all the useful activities of the society, costing the members or fellows large sums of money, it is easy to understand why the Commissioners of Inland Revenue declared the society a "charitable body within the meaning of the Act," and exempted it from liability to income tax. It would be difficult or impossible to correctly estimate the value of the Transactions and Proceedings of the society, published during the last hundred years, but at the very least it can be said that they were the means of preserving and making available the work of numerous capable entomologists, who could not otherwise have recorded their observations. Hardly any of this work could have been made commercially profitable, and without the organized support of such a society the development of the science would have been greatly hindered. When we speak of the benefac-

H. W. BATES

tors of science, wealthy men who have contributed large sums for various purposes, it is appropriate to remember those other benefactors who have employed their available time without financial aid, in working out scientific problems and arranging the materials available, and who have also, in their organized or corporate capacity, furnished great sums of money in aid of scientific progress. These are the people who have really borne the burden of the day.

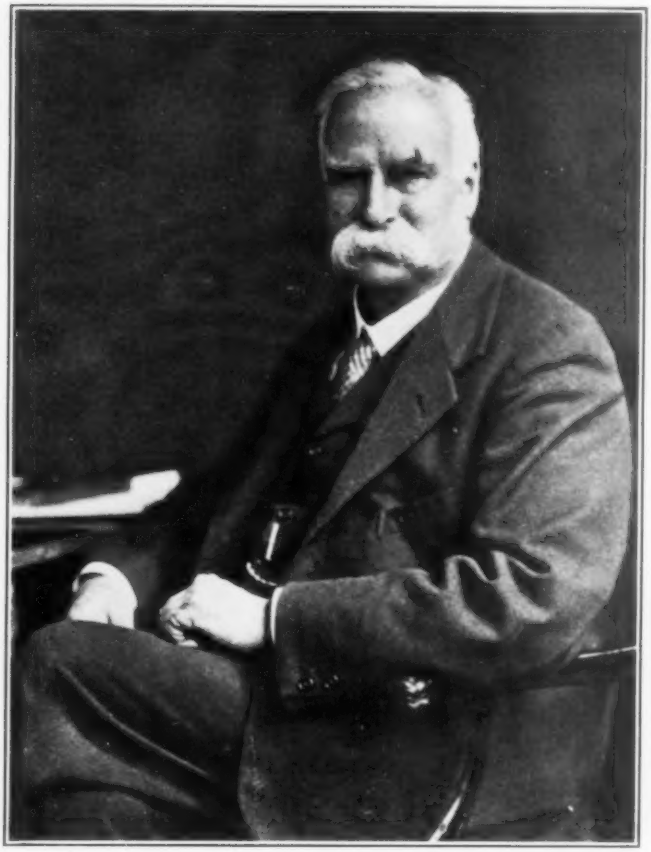
The latest development, more recent than the publication of the history we are reviewing, is the change of the name "by the King's command" to that of the Royal Entomological Society of London. This sounds cumbersome, and rather lacking in any real significance, but it is one of the various steps which have been taken to give the society official recognition. In Australia, a very democratic dominion, one is struck by the number of "Royal" societies. I attended a meeting of entomologists in Brisbane, and we all put on dress clothes, while the chair was taken by the Governor, who represents the Crown. All these frills are not exactly part of science, but if we are sometimes inclined to ridicule them, we are not without regret that our own governors and masters, whom we have elected, have so little appreciation of scientific work. I have a vivid recollection of the semicentennial anniversary of our National Academy of Sciences, held in Washington in 1913. There were memorable addresses by eminent men; the last speech in America by James Bryce, the recollections of the venerable and beloved Weir Mitchell, and others. But the powers that were appeared in the form of Vice-President Marshall, who took the occasion to scold the assembly on account of the unreliable and sometimes dishonest "experts" who appeared in the law courts. The next morning I hastened to get a paper, and saw in great headlines, "Marshall says scientific men can be bought for fifty dollars" (I think those were the exact words), while the really important part of the program was very poorly reported.

Since the success of the society has been so largely dependent on its more eminent members, portraits are given of some of these. The secretary of the society, Dr. Neave, has kindly supplied me with copies of the plates used in the history, and in addition, has loaned several pictures belonging to the society. From all these, the following are selected as the most interesting.

William Kirby, 1759–1850. Sometimes called the "Father of British Entomology," co-author with Spence of the famous "Introduction to Entomology," rich in information concerning the natural history of insects, and the first to make a special study of wild bees. The *Stylops kirbii*, a curious parasitic insect named after Kirby, is the emblem of the society, and suggested the name of the recently established journal.

John Obadiah Westwood, 1805–1893. All-round entomologist; professor at Oxford, occupying the chair founded by his friend, the Reverend F. W. Hope. He occupied a unique and most influential place in the history of entomology, but although he lived more than thirty years after the publication of the "Origin of Species," he never became reconciled to Darwin's views.

Henry Walter Bates, 1825–1892. Bates and Wallace made their famous journey to the Amazons in 1848, and the narrative of Bates, setting forth his observations in tropical South America, is now universally regarded as a classic. His name is closely connected with theories of "mimicry" and warning coloration. In his later years he specialized in Coleoptera and described many new beetles. The picture is made from a



EDWARD BAGNALL POULTON, D.Sc., M.A., F.R.S.
PRESIDENT, 1903–1904, 1925–1926, 1933–.

photograph of Bates, which an artist has fancifully surrounded with objects supposed to be characteristic of the Amazon, producing a very comical effect.

David Sharp, 1840–1922. A most remarkable man, curator of the University Museum of Zoology at Cambridge, and a great authority of Coleoptera. He wrote the two volumes on insects of the "Cambridge Natural History" (1899), perhaps the best general account of the subject ever produced, showing a prodigious knowledge both of the insects and the literature. He prepared a much larger work on the same lines, but most unfortunately, was never able to publish it. He was intimately connected with the *Zoological Record*, first as editor of the Insecta part, and afterward of the entire volume. He had a great deal to do with the *Fauna Hawaiiensis*, giving an account of all the animals known from the Hawaiian Islands. With all this, he was a most interesting personality, and many workers still living were inspired by him.

Frederick Du Cane Godman, 1834–1919. The names of Godman, Osbert Salvin and G. C. Champion will always be remembered in connection with the great "Biologia Centrali-americana," an attempt to discuss the biology of Mexico

and Central America in minute detail, and list or describe all the animals and plants. The scheme was entirely financed by Godman and Salvin. The types of new insects, which were very numerous, are all to be found in the British Museum. The project was not entirely completed; for example, the bees were never described. Naturally, the fauna of such a great and fertile region could not be completely elucidated, and to-day it is probable that the species added to the Biologia lists are as numerous as those there listed, at least in some groups. A serious objection to this splendid work is its great cost. Had it been published in a less expensive style, such as that of the "Fauna of British India," it would have been more useful.

Edward Bagnall Poulton, president of the society at the present time, for many years Hope professor of entomology at Oxford, a position which he has lately relinquished to his friend and disciple, G. D. H. Carpenter. Poulton is primarily interested in the biology of insects, and especially so-called mimicry and protective resemblance, concerning which he has published many interesting new facts. A man of immense energy and enthusiasm, he is not only the life of the meetings, but has inspired and guided many correspondents, especially in tropical countries, who have been led to make all sorts of discoveries, and have been able to get them properly recorded and the species identified with Poulton's aid.

A POSSIBLE INTERPRETATION OF THE QUANTUM

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Introduction

The three aspects of the quantum phenomena which seem to be the most puzzling and most challenging to the imagination are:

I. The revolutionary conception of radiant energy as consisting of definite multiples of a definite unit, Planck's mysterious constant *h*.

II. The reconciliation of the new conception of radiation as discrete and quasi-corpuscular with the older but equally valid conception of radiation as continuous and undulatory.

III. The structure of the atoms and the manner in which a discretely continuous radiation is emitted from and absorbed by them.

I shall consider these three problems in turn and suggest a possible solution for each of them.

I. The Nature of H and the Reason for the Equation E = H · NU

The intensity of light, like the intensity of sound and gravitation, varies inversely as the square of its distance from the source. Yet despite this undenied fact the energy of a light-wave (as measured by the energy given to an electron that is expelled from a photoelectric screen by the impact of the wave) depends not at all upon the distance of the light-wave from its source but solely upon the length of the wave. The shorter the waves the higher the frequency or number passing a given point in a second. And the energy of light of a given wave-length is measured by the product of its frequency symbolized by *nu* and a certain very small fixed quantity. This small quantity is itself the product of energy and time and as such is called "Action." It is the famous constant discovered by Professor Planck. Its value is $6.55 \cdot 10^{-27}$ erg-seconds and its symbol is *h*. Hence the measure of the energy, e, of a light-wave or more properly of an electromagnetic wave of any length is expressed in the equation e = h · nu. The baffling situation thus presented and formulated raises two fundamental and hitherto unanswered questions.

(1) Why does the energy of radiation increase with its frequency?

(2) What is the real nature of Planck's constant *h*?

I trust that the reader will bear with me if I first state my answer to these questions in the form of a little fable or allegory. Allegories do not usually help in matters of physics, but I think that this one will. It will help me at any rate to make plain the conception which I wish to submit for consideration.

When I was very young there lived in my town a prosperous and happy but most peculiar family. There was Henry, the father, who was thin and incredibly tall, a regular giant, in fact. He had two children, Harry, who was a sturdy half-grown boy, and Harriet, a tiny girl but amazingly active for her size and age. There was also a nephew, Cousin Hal as the children called him, a tall slender youth who visited the family almost every Sunday. Last but in some ways most important of all was the mother, who was affectionately known to everybody as Mrs. H. In fact, the whole group was always called simply "the H family," and whether they had a sur-

name or not I do not know. The really striking thing about the family was not what they were named but what they did. They had a game that they always played when they went walking together. I suppose that all of us have played this game in boyhood, but probably only in a haphazard sort of way. You walk along the road and as you walk you kick the little stones that lie in your way, taking them in your stride and noticing how far they go. This was the game played by the H family; but there was nothing haphazard about their method of playing. They had a definite and unvarying procedure and they observed three rather precise conditions which were as follows: (1) They all walked at the same rate but their steps were of different lengths. Henry's step was six feet, Hal's was three feet, Harry's was two feet, and the steps of little Harriet were only one foot. Each member of the family kept to his own length of step and never varied from it. Henry set the pace, which was just six feet a second, neither more nor less. (2) They walked with a sort of limp that made them look as though they were cantering. This was due to their always taking the step in advance with the right foot, which was the one with which they kicked the pebbles, and they merely brought the left foot up even with the right instead of advancing it in turn as in a regular walk. (3) They wore rubber-toed shoes, so constructed that each pebble that was kicked absorbed all the energy of the step regardless of whether the impact occurred early or late in its progress. This necessitated a fresh initiating effort for the next step but produced the same effect on the pebble as if it had been kicked by the foot when moving at a speed equal to its average speed.

It was a delightful experience to see the H family coming down Main Street of a Sunday morning playing their jolly game. Henry's appearance was comical in the extreme, for he wore an expression of preternatural solemnity due to his intentness upon keeping the pace at exactly six feet a second, which happened to be the legal speed limit of the town and was never exceeded by any one. But Hal and the children were very gay and kicked all the pebbles that they could find so long as they could take them in their stride and without deviating. The funniest sight of all was Mrs. H, who, though she did not play the game herself, managed to cooperate in a most important way. She had come from a famous mathematical family, the Plancks of Berlin, I believe, and had inherited a passion for exact measurement. So with surprising agility she went scampering along in front of the rest and by the aid of a queer little contraption that she had devised she measured the mv^2 of most of the stones that were kicked. The results of these measurements were really astonishing and filled the town's population with wonder and perplexity.

In the first place they showed that Harriet's kicks were the hardest of all. Each of her steps was only a foot in length, but her stones had twice the energy of those of Harry, whose steps were two feet long, and three times the energy of those of Hal, who took a full yard in each stride. I must remind you again that the family never varied the differing lengths of their respective steps any more than they varied their speed of progress, though that was the same for all. Now, on comparing the results of the measurements it was found that if you multiplied the *energy* of any pebble by the *time* occupied by the step of the one who kicked it you always got the same result, no matter whose pebble you were considering. Harriet, for example, took six steps to the second, so that the time occupied by each of her steps was one sixth of a second. For

the same reason the time of Harry's two-foot step was one third of a second and of Hal's three-foot step was one half of a second. If we represent the energy of Hal's step (as measured by the energy of the pebble which absorbed it) as 2e and multiply it by the one half of a second or unit of time, t, which his step occupied, the product $\frac{1}{2}t \cdot 2e$ will equal *et*. Harriet's step-energy was, as we saw, three times that of Hal's, *i.e.,* 6e. But 6e multiplied by $\frac{1}{6}t$ equals *et*. And as for Harry the energy of his step was only half that of his sister's, *i.e.,* $\frac{1}{2} \cdot 6e = 3e$, and 3e multiplied by $\frac{1}{3}t$, which was the time taken by Harry for one of his steps, is again equal to *et*. The members of the H family were very much pleased with this result. It gave them a new sense of solidarity that made up for the bewildering and rather distressing differences in the energies of their several kicks. They decided to call the new quantity by the family initial, h, uncapitalized, of course, because it did not represent the first letter of any particular person's name; it was just the family constant.

Quantities of this kind that are got by multiplying energy by time are called "Action." Now in the year in which these happenings occurred there was much talk about Time as a sort of fourth dimension being bound up with Space in somewhat the same way that one spatial dimension is bound up with another. And many people had a queer deep feeling that the hybrid category of *Action* was more fundamental than energy itself, and that in some strange way it bore witness to the new union of space and time in a four dimensional continuum of space-time.[1]

It was easy for all of us to see that if the energy of each step of a member of the H family when multiplied by its time produced the quantity *h*, then conversely the energy itself could be expressed as the product of *h* and the reciprocal of the time, which latter will coincide with the frequency or number of steps per second, usually symbolized by the Greek letter nu. For if $et = h$ and $t = \frac{1}{nu}$ then $e \cdot \frac{1}{nu} = h$ and $e = h \cdot nu$. Thus Harriet's time for a step being one sixth of a second, the reciprocal of which is 6, her energy will be equal to 6h. With Harry and Hal the frequencies will be 3 and 2, respectively, and the energies of their respective steps will be 3h and 2h; and in general the energy of any such step will be expressed by the equation $e = nu \cdot h$.

But just what was the real nature of this *h* and why did multiplying it by the frequency of the step give the energy of the step? In other words, why should the energies severally associated with the members of the H family be the reverse of what you would naturally expect, Harriet's more than Harry's and his more than that of his tall cousin? These questions fascinated me and I kept thinking about them when I ought to have been doing my regular stuff. At last I determined to get a stop-watch and check up on the various factors involved in the situation. Thus equipped I took up a good position on the sidewalk and observed very closely the steps of the family as they cantered past me. I noticed how much more quickly Harry and Harriet completed their steps than Hal and Henry; but of course that increased quickness of stepping didn't explain anything, because the steps of the little ones were that much shorter. Why should Harriet increase her energy by

[1] "Multiplying [energy] again by hours would seem a very odd sort of thing to do, but it does not seem quite so strange when we look at it in the absolute four-dimensional world. Quantities such as energy which we think of as existing at an instant belong to three-dimensional space and they need to be multiplied by a duration to give them a thickness before they can be put into the four-dimensional world."

See Eddington: "The Nature of the Physical World" (p. 180).

making a step six times as quickly as her father if in that step she only went one sixth the length of his step? But one day I got a clue. I noticed that the time taken by each step was divided into a *resting-time,* during which the foot was on the ground, and a *going-time,* during which it was moving through the air. Though each of Harriet's resting periods was actually shorter than that of the others, nevertheless there were more of them, and in proportion to the total time of her step each of her resting periods was longer than that of the others. I worked on this aspect of the situation, with my stop-watch recording the moving-time and the resting-time for the various steps, and this was what I found. Henry's resting-time was a very small fraction of a second, which for simplicity I will designate by the letter R. His going-time was consequently $1 - R$, and the velocity of his foot while it was moving was therefore $\frac{6}{1\text{–}R}$ feet per second. The going-time of Hal, who took two steps per second, was $(\frac{1}{2})^2 \cdot (1\text{–}R)$ in each step, so during the entire second he was on the go $2 \cdot (\frac{1}{2})^2 \cdot (1\text{–}R) = \frac{1}{2}\ (1\text{–}R)$; in other words, for just half the time during which his Uncle Henry's foot was moving, so that in order to keep up with his uncle his foot had to move just twice as fast as the latter's foot. Harry, who took three steps a second, was on the go $(\frac{1}{3})^2 \cdot (1\text{–}R)$ in each step and hence $3\ (\frac{1}{3})^2 \cdot (1\text{–}R) = \frac{1}{3}\ (1\text{–}R)$ in each second, which meant that having exactly one third of his father's traveling time he had to travel three times as fast. In the same way, Harriet's total traveling time was $6 \cdot (\frac{1}{6})^2 \cdot (1\text{–}R)$ or just one sixth of Henry's traveling time, with the result that if she herself was to go as fast as her father, her foot had to go six times as fast as his foot. In short, I discovered the general law that I had been searching for. In any family of steppers like the H family there is an *internal velocity* of each stepper which is proportionate to the frequency of his steps per unit of time and hence can be obtained by multiplying that frequency by the *internal velocity* of a leader or Standard Stepper whose frequency of stepping is one per second. Let us denote the *internal velocity* of the standard stepper (whether actually existing or only potential does not matter) by $V = \frac{C}{1\text{–}R}$, where C is the length of the standard step and R is the portion of the unit of time during which the foot is at rest and therefore (1–R) the time in which the foot is moving. Then, using v to denote the *internal velocity* and *nu* to denote the frequency of any other stepper, we have as a true equation

$$v = nu \cdot V \text{ or } v = nu \cdot \frac{C}{1\text{–}R}$$

In the light of this equation it was no longer surprising that little Harriet kicked her pebbles the hardest of all the family, for her feet moved the fastest not *in spite* of but *because* of her steps being the shortest. Harriet was indeed like an automobile which had to make an average speed of sixty miles an hour but which had to stop for traffic lights every ten miles. You can imagine how much faster such a car would have to travel in between the stops, as compared with another car making the same general average of sixty miles an hour but only obstructed by traffic lights once each sixty miles. The average "internal velocity" of the former car, by which I mean the velocity *between each of its stops,* would be six times as fast as that of the latter, and the energy which it would impart to either a pebble or a pedestrian that got in its way would be correspondingly greater and sadder.

I was feeling very happy over this analysis of the situation, knowing as I did that when a thing's velocity increased it gained in energy, when sud-

denly all my happiness vanished and I spent a most perplexed and disconsolate half hour. For it came over me that while the velocity of the step varied with its frequency the energy of a moving thing varies not with the velocity itself but with the velocity squared. It was such an oversight as only a child would make and my chagrin and humiliation were bitter indeed. And then suddenly I was all right again, for I bethought me of a perfectly obvious fact that I had completely forgotten to take account of, the fact, namely, that the *mass* of the leg and foot of the stepper varied directly with the length of his step or inversely with its frequency. The tiny leg and foot of Harriet, for example, were one sixth the mass of her father's, Hal's were a half, and Harry's were a third of that mass, therefore the energy mv^2 will increase with the *first* power of v because the other power of v will be neutralized, so to speak, by the decrease of the mass m. Thus, if we call Henry's energy in each step mv^2 and if we bear in mind that the mass factor in Harriet's step is $\frac{1}{6}m$, in Harry's $\frac{1}{3}m$, and in Hal's $\frac{1}{2}m$, then Harriet's energy will be symbolized by $\frac{1}{6}m(6v)^2 = 6mv^2$; Harry's will be $\frac{1}{3}m(3v)^2 = 3mv^2$; and Hal's will be $\frac{1}{2}m(2v)^2 = 2mv^2$; and in general the "step-energy" of any member of the family will be $\frac{1}{nu}m(nu \cdot v)^2 = nu \cdot mv^2$.

Up to now we have not spoken directly of the energy of Henry's steps. Whether from an old-fashioned conjugal piety or from some special difficulty, real or imagined, Mrs. H. never measured the energy of her husband's steps as contained in the pebbles that he kicked. But if she had she would of course have found them in agreement with the general formula

$$e = h\,nu$$

And as in Henry's case $nu = 1$ his step-energy was h times 1 or simply h. In short when *energy* is multiplied by *time*, and *time* is $1/nu$, and nu is 1, then the product of *energy* and *time* is the same as—or is measured by the same number as—the energy itself. Of Henry we may say that his *energy* and his *action* were the same thing, namely h. Now it is all very well to call Henry's step-energy h and to note that the step-energies of the members of his family were all discrete multiples of that energy, nu, the discrete multiplier, being the frequency which determined the velocity which determined the energy of movement within each step. But we must also remember that Henry's energy, like all energies, can be expressed as one half the product of a mass and the square of its velocity. Hence we can call Henry's step-energy not only h but $\frac{1}{2}mv^2$; and we must ask what is the m and what is the v^2 which when multiplied together and divided by 2 are equal to h. The mass factor is of course the mass of Henry's leg and foot, and we will not bother about that just yet, as it pertains too exclusively to the secondary details of our story. But the v^2 is more important because it is the square of the velocity of a step *whose internal speed is critical in any given system of measurements,* being the speed of the step of a person who takes but a single step in each unit of time.

My fable has been long, but its application can be very brief. The H family, or rather the steps taken by its members, are of course the fictional analogue of the family of light-waves which range in length and frequency from the longest of the radio waves to the shortest of the gamma waves. They all travel at the same constant velocity, which is, however, not 6 feet a second, but 300,000 km a second.

The pebbles that were kicked off the ground and that received and registered the energy of the stepper who kicked them, are the electrons that are knocked off the photoelectric screen with a velocity that embodies the energy of the impinging light-waves. As Mrs. H. in

the fable measured the energy of the pebbles—and hence of the steps which caused their motion—by her "contraption," so does the physicist, by compelling the electrons to pass through his magnetic and electrostatic fields, succeed in measuring *their* energy and hence indirectly the energy of the light-waves which caused their motion. Corresponding to Henry with his six-foot steps there is a potential light-wave whose frequency would be one a second, whose length would be 300,000 km and whose energy would be the real *h* as the energy of Henry's step was the fictitious *h*. There is nothing intrinsically peculiar about this wave as such, but in our system of measurements it is most peculiar because its energy will figure as the mysterious unit of which the energy of all other waves will be discrete multiples, as expressed in the famous equation $e = nu \cdot h$.

The energy of the standard or unit wave will be $\frac{1}{2} M \left(\frac{C}{1-R}\right)^2$, where C is of course the velocity of light, R the resting-time of such a wave, (1–R) its going-time, and consequently $\frac{C}{1-R}$ its internal velocity.

As for the mass factor, M, it would be a real but periodically intermittent condensation (186,000 miles long) of the ether that was dear to Queen Victoria and her subjects. But if any one thinks that it would be better to describe this real but regularly intermittent mass-factor in a light-wave as a periodically recurrent non-Euclidean warp in space or space-time he is welcome to do so.

My theory can be summed up as follows: All light-waves have the same *external velocity* or speed of propagation, but each of them has an *internal velocity* and hence an internal energy that is different for different waves, being proportionate to the frequency or shortness of the waves in question. The validity of this conception rests upon my fundamental hypothesis that a light-wave is analogous to the step of a man walking in a certain manner, in that its total period is divided into a *resting-time* which intervenes between the successive steps or pulses of propagation, and a *going-time* in which the *internal velocity* of the pulse or step passes from zero to its maximum and back to zero. The greater the frequency of a wave per second the greater the number of its resting periods *during* that second, and the less the time that is left in which to do its traveling, and hence the faster it must go if it is not to drop behind. In short, if a wave of frequency *nu* is to keep up in the procession with all waves and in particular with a standard wave whose frequency is one per second, its individual pulses will have to go *nu* times as fast as those of the standard wave. Its average *internal velocity* will thus be measured by its frequency, and its resulting energy will equal one half the product of its *internal velocity* squared and its mass. But if the mass-factor of a wave does itself vary inversely with its frequency, which was our assumption, then its energy will be equal, not to the second power, but to the first power of its frequency multiplied by the energy of the standard wave. If Planck's mysterious constant *h* is simply the energy of the standard electromagnetic wave of unit frequency then the energy of any other wave will be *nu* times h. My assumption that the mass-factor varies inversely with the frequency and directly with the length of a wave is not an arbitrary one, because the shorter the wave the less the volume of spatial field that undergoes the periodic concentration or warpage that constitutes the mass-factor of a wave. Our theory suggests the curious possibility of there being a quantum, or something analogous to it, in every system of waves.

Having now stated my interpretation

of the nature of h and the reason for the equation $e = h \cdot nu$, I turn to the second of the three problems of the Quantum.

II. The Reconciliation of the Undulatory and the Corpuscular Aspects of Radiation

Something happens within an atom and immediately there is emitted from it radiant energy which travels away from its source with a velocity of 300,000 km per second. These units of radiation possess many of the characteristics of waves or periodic changes. Not only do they seem to be of different length and frequency and to travel always at the same rate, regardless of the motion of their source, but they exhibit the phenomenon of interference, counteracting and enhancing one another. Now if a wave goes out in all directions from its source, we can think of it as spread over the surface of a sphere, a sphere that is expanding with the speed of light. One would suppose that the intensity of such a wave should vary inversely with the square of its distance from its source. Covering a larger and larger area as its distance grows, there will naturally be less and less of it for each unit of area. Sooner or later a physicist will hold up a photoelectric screen and tap this wave to test its energy. The source of the wave may be at the other end of his laboratory or at the other end of the Milky Way, but in either case the entire energy that issued from the atom will be instantly mobilized from all over the spherical surface of the advancing wave and delivered intact to the electron whose movement will record the transaction and the amount received. Now when one tries to think of this instantaneous reconcentration of energy, imagination is challenged and reason baffled to an extent unparalleled in the history of science. Sir William Bragg has aptly compared the situation to one in which a wave is aroused by a log dropped into the water and spreads out for miles in an ever-widening circle of ever-diminishing intensity. Finally this ripple comes into contact at one point of its vast circumference with another log and suddenly reassembling all its scattered energies shoots it up into the air with a force as great as that possessed by the original log which far away and hours ago had started the process.

Confronted with such a paradox we tend to abandon the conception of light or radiation as consisting of *waves* at all. The fact that distance has no effect on the energy suggests that light is composed of some kind of corpuscles. If that were so we could understand how these corpuscular elements of radiation, being unretarded by friction, could maintain unchanged their velocity and therefore their energy throughout any distance. As to the fact that while their energy does not depend upon their nearness to the source it does depend upon their shortness or frequency—we might at least hope to interpret that as due to discrete differences in the mass of such corpuscles. The so-called shorter light elements might, for example, contain proportionately larger multiples of some ultimate unit of radiant mass. What we call the *intensity* of the radiation or the brightness of light would then be purely a *group-phenomenon,* due to the number of corpuscles that in a unit of time impinged on a unit of surface. And this number would vary inversely as the square of the distance, as intensity or brightness should do. From such a theory it would follow as a corollary that the intensity of light would be increased either by increasing the number of radiating units at the source or by lessening the distance of the recipient from the source; and the effect of such increased intensity on the photoelectric screen would be what as a fact we find it to be, namely, an increase in the

number of electrons shot off and not an increase in their *velocity*.

The corpuscular theory, however, while thus capable of explaining many of the properties of radiant energy, still appears incapable of explaining such ineradicably undulatory properties as interference of radiations with one another and the continuity of their incidence upon a receiving surface such as the lens of a telescope. If light consisted of separate corpuscles their increased distance from one another as they diverged or scattered from their center of origin (like a charge of bird shot from a gun) should become sufficiently great to make its effect appreciable in the form of gaps or discontinuities to an observer who was as far from some of the observed stars as we are. But though such an effect has been looked for, it has not been found. Light from the most distant sources preserves its continuity of frontal surface just as little waves would and just as little corpuscles wouldn't and couldn't.

There is moreover against this corpuscular theory another objection, which is interesting in itself and which possesses at least an *ad hominem* force. *If light were composed of corpuscles, either the Ritz Hypothesis would be true or else the Doppler effect would be a one-way affair and would reveal to us an Absolute Motion expressed as an empirical difference between the situation in which a luminous source moves toward an observer, and the reverse situation in which the observer moves toward the luminous source.* For in the latter case we should meet the light corpuscles with more force than if we stayed still, and thus be able to observe an increase of their energy as a Doppler shift toward the violet. But if the light-giving object was moving toward us and if the speed of the corpuscles emitted by it was unaffected by the speed of their source they would reach us in greater *number* per unit of time but not with greater individual *velocities*. And thus the photoelectric screen would fail to register any shift toward the violet. The only way to lay the specter of Absolute Motion would be to accept Ritz's Hypothesis that light being corpuscular, its velocity, like the velocity of an ordinary projectile, varies with the velocity of its source. It would *then* make no difference whether we moved faster toward the corpuscles or whether they moved faster toward us. The shift toward the violet would in the two cases be equally observable in the increased energy of the individual electrons that were knocked off the photoelectric screen. But this way of restoring symmetry to the Doppler effect would be spurned by most physicists and astronomers. For whether they are Einsteinian Relativists or Newtonian Classicists they appear to agree in believing that De Sitter's deductions from the observations of double stars, as well as certain recent observations of the aberration of light from distant nebulae, are conclusive disproof of the assumption that the velocity of light varies with the velocity of the source. To all believers in Einstein's Special Theory of Relativity the implications of the corpuscular theory for the Doppler effect should have a fatally decisive though *ad hominem* force. For in accepting the corpuscular theory they would have to couple their acceptance either with a belief in the Ritz Hypothesis or with a belief in Absolute Motion.

The whole situation is in a sense desperate. And desperate situations call for desperate remedies. One such remedy is characterized by Sir Arthur Eddington as the Sweepstake Theory. The situation that leads to the theory and the theory itself are set forth by him in "The Nature of the Physical World" (pp. 185–190), from which I quote the following passages:

> The pursuit of the quantum leads to many surprises; but probably none is more outrageous to our preconceptions than the regath-

ering of light and other radiant energy into h units, when all the classical pictures show it to be dispersing more and more. Consider the light-waves which are the result of a single emission by a single atom on the star Sirius. These bear away a certain amount of energy endowed with a certain period and the product of the two is h. The period is carried by the waves without change, but the energy spreads out in an ever-widening circle. Eight years and nine months after the emission, the wave-front is due to reach the earth. A few minutes before the arrival some person takes it into his head to go out and admire the glories of the heavens and—in short—to stick his eye in the way. The light waves when they started could have had no notion what they were going to hit; for all they knew they were bound on a journey through endless space, as most of their colleagues were. Their energy would seem to be dissipated beyond recovery over a sphere of 50 billion (10^{12}) miles radius—How is it managed? Do the ripples striking the eye send a message round to the back part of the wave saying "We have found an eye, let's all crowd into it!". . . . Suppose that the light-waves are of such intensity that, instead of each atom absorbing one millionth of a quantum one atom out of every million absorbs a whole quantum. That whole quanta are absorbed is shown by the photoelectric experiments already described. It would seem that what the light-waves were really bearing within reach of each atom was not a millionth of a quantum but a millionth chance of securing a whole quantum. The wave-theory of light pictures and describes something evenly distributed over the whole wave-front which has usually been identified with energy. Owing to well-established phenomena such as interference and diffraction it seems impossible to deny this uniformity, but we must give it another interpretation; it is a uniform *chance of energy*. Following the rather old-fashioned definition of energy as "capacity for doing work" the waves carry over their whole front a uniform chance of doing work. It is the propagation of a chance which the wave-theory studies.

Now there are two objections to this Sweepstake Theory. First there is the one which Eddington himself goes on to state, but which I take the liberty of presenting in my own words. How does it happen that the first atom to touch the expanding spherical surface of probability-waves always draws the winning ticket and receives the prize of actual energy? If a conjurer on the stage threw out over the heads of his audience a scattering pack of cards, and if the member of the audience who caught the first card regardless of where he was sitting always found it to be the ace of spades, we should have to draw one of two conclusions. Either the conjurer had this man "planted" in the theater as a confederate and knew just where he was sitting, or else every card in the pack was an ace of spades. The latter conclusion would be barred out by making sure (as we actually do) that the conjurer had only one of the prize-winning aces in each pack that he threw out. The other conclusion as to the presence of a confederate would remain. And it would have its analogue in the fascinating but ultra-quixotic theory of Gilbert Lewis, that an atom can not muster up courage to emit a vibration until it knows exactly where and when that vibration will be received. The recipient scientist with his eye or his photoelectric screen may be trillions of miles away in space and not due to be born for hundreds of years after the light issues from the star. But according to the Special Theory of Relativity, in the case of a light ray, the spatial and temporal distances cancel one another, $ds^2 - dt^2 = 0$, and between the start and the finish of the ray there is a kind of contact in space-time, a mystical *rapport*, which is the basis for Lewis's feeling that the atom must "know" where its light will land before it emits it. I do not know what Lewis would say to the case of a physicist who, having read his theory, decided to thwart destiny and instead of holding up his photoelectric screen at the time and place he had intended before reading should decide to leave the date and location to be determined by the throw of dice. I should think Lewis would have to say of such a situation that Fate could not be thus circumvented and that the prophetic insight of the atom in the distant galaxy would have been so keen that it would

have foreseen or seen through the reading of Lewis' book by the scientist, the casting of the dice, and their resulting configuration determining the time and place of the electronic recipient of the light—despite the fact that all these events happened "after" the light had been irrevocably started on its journey. Now, notwithstanding my friendship and high respect for Gilbert Lewis, I must really ask to be excused from believing this. If it is true, as Lewis believes, that such an absurdity is actually implied by Einstein's Special Theory, then all I can say is, "So much the worse for the Special Theory."

But even if we waive this objection to the Sweepstake analogy we are immediately confronted with another: What is to become of all the other chances of energy that have been propagated from the atom after the winning chance has been actualized? Lottery tickets that have been declared unsuccessful are at least worth the paper they are printed on and they continue to occupy space, albeit in the scrap baskets of their unsuccessful owners. But these unsuccessful *probabilities* that have been traveling outward with the velocity of 186,000 miles a second and that are dispersed over the surface of the huge sphere have nothing to do and nothing to be. They lapse into absolute nonentity on the instant that the lucky ray conveys its freight of actual energy to the receiving electron.

In view of all this it seems to me that the Sweepstake Theory completely fails and that, as Sir William Bragg has so happily phrased it, we are left with the necessity of teaching the classical theory of light on Monday, Wednesday and Friday and the quantum theory on Tuesday, Thursday and Saturday. Both can not be, and each must be, true. Such a situation is so outrageous that no one, not even the most extreme positivist or empiricist can "take it lying down." Any one who has in the veins of his mind a single drop of the red blood of reason must demand satisfaction in the form of some conception of what it is that is really happening to produce these seemingly incompatible sets of appearances.

When doctors disagree or fail to cure there is a chance for the quack to peddle his nostrum; and as a poor but honest quack I want now to proffer my nostrum. At worst it will do no harm.

Let us suppose that the mysterious entity that issues from an atom is a condensation in the ether (or a non-Euclidean warp of "space"), that is shaped like a cone but with so slender an angle of divergence as to approximate a cylinder, and that it moves outward from the atom at the speed of light. The path of this movement or the volume generated by it is a conical sector of a sphere whose center is the center of the nucleus of the initiating atom and whose base or advancing frontal surface is as distant as may be. The movement outward through the volume of this expanding cone is a periodic movement. It is the movement of an advancing wave. I shall assume that this movement consists of progressively alternating "twist-thrusts" like those of a cork-screw—clockwise then counter-clockwise, then clockwise, then counter-clockwise, and so on.

Perhaps I can bring my idea more clearly to your minds if I simply ask you to picture a long slender cone cut transversely into sections of equal length but remaining *in situ, i.e.,* as they were before they were cut. Paint these sections alternately black and white and think of their contact surfaces as possessing a cog-like mechanism such that shortly after the right-hand or clockwise twist-thrust of one completes itself there will begin a counter-clockwise twist-thrust in the next. Then imagine the series of periodic and alternating

twist-thrusts to start from the apex of the cone and travel outward, and the thing that you would see advancing outward and expanding as it went along and through the whole cone would be the kind of thing that according to my hypothesis a light-wave is—a thing that would wriggle or worm or *squirm* its way through space at a velocity of 186,000 miles a second. Let us call the light-wave as thus conceived a "squirm." Squirms could be of various lengths, as light-waves are; and while the speed of the procession as a whole would be the same, irrespective of the length or correlated frequencies of the constituent squirms, the *internal velocity* of each squirm (which is the measure of its energy) would vary inversely with its length and directly with its frequency. For just as in the family of steppers in the fable, with which my paper began, the total period of each squirm would be divided into a *going-time* and a *resting-time*. The shorter the squirm the greater the number of its resting periods and hence the faster it would have to go during the time when it was going. And as the mass of a squirm varies inversely with its *internal velocity*, the internal energy or mv^2 of the squirm varies directly only with the first power of that velocity which is in turn determined by its frequency and will therefore be expressed by multiplying its frequency, *nu*, by a constant. That constant is *h*, which is the unit energy of the standard or critical squirm which in our system of metrical units has a length of 300,000 kilometers and a frequency of one per second. All squirms of frequencies greater than one or multiples of one will have energies that are corresponding multiples of *h*.

Now the foregoing characteristics of the light-squirms as to mass, length, frequency, external velocity and *internal velocity* are characteristics which they share with all waves.

First, though the mass of any squirm is a function of its length and hence remains unchanged no matter how far out from their source squirms of a given length (that of red light, for example) may have traveled, yet the *character* of the mass changes; its density or intensity of concentration decreasing as its volume increases, for it is obvious that the truncated sections of a cone, if they are of constant length, take up more space the further they are from the apex.

Second, a squirm of radiant energy, as I conceive it, will "vibrate" in a direction nearly but not quite perpendicular to its direction of propagation. But this so-called vibration will consist of alternating rotations or twists which will lie in the ever-varying plane of a shallow whorl to which the "ray" or longitudinal dimension of the cone is almost normal. Hence, when a squirm strikes the electron on the photoelectric screen it will cause it to move off sideways rather than in the line of the light ray.

Thirdly, the advancing front of the squirm will occupy the same proportion of the surface of a sphere at one distance as at another. And a group of squirms going out from a light-emitting center will always remain as adjacent to one another as they were at the start. They will not possess the fatal capacity to scatter that disqualified the corpuscular hypothesis. They will be true waves, and as such they will exhibit the requisite phenomena of undulatory interference, no matter how far from their source. But at the same time that they preserve their continuity as a group they will also preserve their quasi-corpuscular discreteness and integrity as individuals. The squirm is not only "big" enough to enter the astronomer's telescope in the way it does, it is also "small" enough to be sucked in by the electron on the photoelectric screen of the physicist. No

matter how large its frontal cross-section and the radius of its twist may be, the twist itself will be as much of a single unit as when it was first emitted and as such can impart all its energy to the electron almost on the instant of contact with the same ease with which a large top could impart its energy of spin to a small object with which it came into fatally intimate contact and in such a way that what was velocity of spin in the giver would become velocity of translation in the receiver.

In short, because of its seemingly harmonious combination of the undulatory characteristics of classic light with the corpuscular characteristics of quantic light, I respectfully nominate my "squirm" as a candidate for the high office of "wavicle," the felicitious name suggested by Eddington for that blend of wave and particle which is the great desideratum for light as known to-day. It was the reconciliation of these apparently contradictory properties of radiation that constituted the second of our three problems of the Quantum. Let us now turn to the third and last of the puzzles—the nature of the emitting atom, tiny source of all the mischief.

III. The Nature of Atoms and the Manner of Their Discrete but Continuous Emissions

I accept the hypothesis proposed by Professor Louis King and by other physicists that the electrons spin or rotate on their axes. I supplement this hypothesis with the further one that the *protons* also spin, and I propose to employ these hypotheses in a manner that so far as I am informed has not been suggested before.

An electric charge in rotation becomes a magnet with a north pole and a south pole. Hence the spinning protons and electrons are related to one another by magnetic as well as by electrostatic forces. There are of course an infinity of angles possible between the axes of any two such spinning particles, but I wish to limit my discussion to the single case in which the axes of spin are exactly, or very nearly, in line. I adopt this limitation partly to avoid unmanageable complexities and partly because I suspect that two spinning charges, freely interacting, would arrive at this configuration sooner or later whatever might have been the initial inclination of their axes in relation to one another. Observing this limitation, we can picture our pair of spinning particles with their axes end to end or like a pair of spinning tops one above the other; and there would then appear to be four different situations to be taken account of.

(1) Two particles of dissimilar electric charge with similar magnetic poles adjacent.

(2) Two particles of dissimilar electric charge with dissimilar magnetic poles adjacent.

(3) Two particles of similar electric charge with similar magnetic poles adjacent.

(4) Two particles of similar electric charge with dissimilar magnetic poles adjacent.

These situations may be symbolized thus:

	S		N		S		S		N		N
	–		–		+		–		+		–
	N		S		N		N		S		S
1	N	2	N	3	N	or	N	4	N	or	N
	+		+		+		–		+		–
	S		S		S		S		S		S

In analyzing these four situations there is a most important principle which we must keep before our minds:

When the dimensions of two magnets are negligibly small in comparison to the distance between them, the magnetic force, whether of attraction or repulsion, varies inversely not with the second power but with the third power of the distance of the magnets from one another.

Inasmuch as the *electrostatic* force of attraction or repulsion varies inversely with the *square* of the distance it follows that for our particles, which are both charges and magnets, the electrostatic force will be the dominant determiner of behavior at relatively large distances (the magnetic force diminishing more rapidly with increase of distance than the electric) while at relatively small distances the magnetic force will be the dominant determiner of behavior, for it will increase more rapidly than the electric force with the decrease of distance; and finally, *when the electric force is attractive and the magnetic force is repulsive*, there will be a critical distance at which the two forces will balance.

In the light of these facts we can see at once that in situation number 4 the two protons or electrons, if by themselves and uncemented by a third particle of opposite charge between them, will repel one another and execute an unending reciprocal retreat; for they would ordinarily never have a chance to get near enough to have their magnetic attraction dominate their electric repulsion.

In situation number 3 where the two similarly charged particles suffer at all distances a double repulsion, both magnetic and electric, their retreat from one another will be even more obvious.

In situation number 2 we have the reverse of number 3. Instead of suffering a double repulsion the dissimilar electric charges with their dissimilar magnetic poles adjacent will enjoy a double attraction and will cuddle close into a nuclear nest.

We now turn to situation number 1, which is by far the most interesting of the four that are listed in the diagram. Here we have two particles with dissimilar charges but with similar magnetic poles adjacent. We have already remarked that such a blend of electric attraction and magnetic repulsion means that when the distance separating the particles is great the electric force will predominate and the particles will converge; but when the distance is small the reverse will be true, magnetic force will predominate and the particles will diverge. Between the "great" distances and the "small" distances there will, however, be an intermediate distance at which the opposed tendencies will just balance. In the hydrogen atom, for example, with its single proton as nucleus and its single "planetary" electron there will be a critical distance between them, at which the magnetic repulsion will equal the electrostatic attraction. Representing this critical distance by D, the magnetic force by Fm, and the electrostatic force by Fe, we have

$$\frac{Fm}{D^3} = \frac{Fe}{D^2}, \quad Fm = D \cdot Fe, \quad D = \frac{Fm}{Fe}.$$

If by some external influence the distance of the electron from the nucleus is made longer, the magnetic repulsive force will decrease more rapidly than the electrostatic attractive force, and therefore the electron will tend to snap back inward. If, on the other hand, the distance is made shorter, the magnetic repulsion will increase more rapidly than the electric attraction and the electron will tend to snap back outward. The two elements of the system, united as they are by their diverse forces, will constitute a sort of coiled spring such as one finds in chairs and sofas. It will offer resistance both to compression or shortening and to expansion or lengthening. This resistance will be as gentle as you please for slight changes in either direction, and proportionately stronger for greater changes.

I wish now to pass from these deductions from my primary hypothesis and to propose certain further and secondary hypotheses. I make these subsidiary hypotheses or guesses very diffi-

dently and in the hope that if some or even all of them should prove to be not good they may nevertheless suggest to those more competent than myself hypotheses that will be good.

First, then, let us suppose that the proton-electron system above described can vibrate in halves, thirds, quarters, fifths, etc., of its length. Such vibrations we will call its "tones." And we will assume further that the system can entertain at least for a time several or all of them simultaneously, as a superposed hierarchy of periodic motions.

Secondly, let us suppose that that which in the first section of our discussion we called the "internal velocity" of the step or wave varies (when *within* the spring) *not inversely but directly* with the length of the step or wave. So that when the spring was vibrating in thirds, the *internal velocity* of those vibrations would be as much greater than the *internal velocity* of vibrations that were fourths as one third is greater than one fourth, and in general that the *internal velocities* of vibrations whose lengths were $1/n$ and $1/(n+r)$ would be to one another as $1/n$ is to $1/(n+r)$. This is not as arbitrary a supposal as it might seem, for it is certainly true that the further you jam down (or stretch up) a coiled spring the harder and faster it will fly back. The greater the length of the periodic displacement the greater the velocity of return.

Thirdly, let us suppose that the mass factor in these periodic movements does not vary directly with the length, and inversely with the internal speed, as in the case of the light-waves outside the atom, which we discussed previously, but that it is *constant*. It will be as though the mass of the whole system entered into each and all of its vibrations.

Now let us examine the implications of our supposals or postulates. We notice that if the atom be conceived as a spiral spring, its vibrations are in their lengths and velocities

$$1/1,\ 1/2,\ 1/3,\ \ldots$$

which means that the energies of these vibrations will be the products of a mass factor, M_p, characteristic of the spring itself, and the squares of the several velocities; thus

$$E = \tfrac{1}{2} M_p \cdot \left\{ (1/1)^2,\ (1/2)^2,\ (1/3)^2 \right\}$$

These energies will travel in both directions, up and down the spring, from the nucleus out to the electron, and back in from the electron to the nucleus. Now any one of these vibrations, if left to itself, would go like a shuttle-cock between two battledores, peaceably outwards and back through the spring forever. There would be no friction to slow it down and no way for it to *get out*. But when one vibration meets or overtakes another of a different length and rate—what then? Well, if the interference occurred within the atom, *i.e.*, between the nucleus and the electron, I suppose that they would pass right through each other as proper waves do, and be none the worse for it, their integrities remaining unscathed by their transitory union. Perhaps one of Maxwell's demons, if he lived in the atom, might hear some beats or difference-tones, but that would be all. Nothing would get to the ears of the outside world. But now suppose that their interference occurred at the electronic terminus of the trip. The vibration $1/n$ just arriving meets the vibration $1/(n+r)$ which is just starting back. The electron which constitutes the outer end of the spring can not accommodate the two vibrations by moving in opposite directions at the same instant. The situation is serious, and so far as I can see, the lesser vibration, whose energy was $\tfrac{1}{2} M_p \cdot \left(\dfrac{1}{n+r}\right)^2$, would neutralize such part of the stronger vibration as was

equal to itself, leaving an unneutralized remainder whose energy would be equal to $\frac{1}{2} M_p \cdot \left\{\frac{1}{n^2} - \frac{1}{(n+r)^2}\right\}$. This remainder, a sort of "difference-tone," would have nothing to do but *slip off into space,* as a new-born squirm or light-wave, and go on about its business. The energy of the young squirm, like that of any squirm, would be equal to Planck's constant, h, multiplied by its own frequency, *nu*. But as witness to the values of its parents of whose unhappy union it was the fruit, its energy would also be equal to $\frac{1}{2} M_p \cdot \left\{\frac{1}{n^2} - \frac{1}{(n+r)^2}\right\}$, where n and r are any positive integers.[2] The factor M_p would have just the value that was necessary to make h · *nu*, the "difference-tone," equal to the *difference between* the two "tones," $\frac{1}{n}$ and $\frac{1}{n+r}$, from which it originated. And that value would be characteristic of the type of atom emitting the radiation. From these considerations we can see that a light-wave coming from an atom is not merely a member of the general tribe of squirms but also a member of a special family as symbolized by the subscript letters in M_p, M_q, M_w, etc. That special family in the case we are considering is the group of light-waves registering as lines in the spectrum of hydrogen. It is a large family, containing perhaps an infinite number of members. But the members are by no means a continuum composed of all possible values. They have only such values as are represented by the differences between pairs of *terms* in the series.

Let us glance briefly at the prospective history of a squirm such as the one whose birth we have described. It glides out into the ether and swims freely but in the direction determined by the line that joined the proton and electron at the instant of its leaving them. It squirms its way along, with alternating twist-thrusts, at the rate of 186,000 miles a second. Its volume gets larger as it occupies successively the larger and larger truncated sections of the cone which is its path and from whose apex it originated and toward whose infinitely distant base it travels. But this growth in volume is balanced by an equal diminution in density. As it grows bigger it becomes more and more tenuous, with the result that since its length and *internal velocity* do not change, its energy and mass also remain constant.

There are two alternative destinies in store for every squirm; one, ignominious and tragic, the other happy if not glorious. The ignominious fate that may befall a squirm is to be swallowed by an electron and utilized as food to give the electron energy of translation. In having its own periodic motion thus transformed into the electron's motion of translation, its specific structural identity is permanently lost and only its quantity is conserved—destined perhaps to be measured by a scientist if the devouring electron is located on a photoelectric screen. Let us suppose, however, that the squirm escapes this death by absorption. In the course of its travels it will meet with various atoms. In some of these atoms the defining constant, M_q or M_w (differing from its own defining constant M_p) will be such that no product of the form

$$\tfrac{1}{2} M_{q,\cdot w} \left\{\frac{1}{n^2} - \frac{1}{(n+r)^2}\right\}$$

will be equal to $\frac{1}{2} M_p \left\{\frac{1}{n^2} - \frac{1}{(n+r)^2}\right\}$ or the particular value of h · *nu*, which is the energy measure of the squirm in question. Atoms of this kind will neither absorb and devour our squirm, nor will they welcome him. He will be courteously turned away, and transmitted or simply reflected by them. Some day, however, he may have the

[2] I believe, however, that usually if not always $r = 1$.

luck to meet with an atom of his own family, a hydrogen atom, one line in whose spectrum belongs to him. It will be then that he will have recourse to his birth-certificate and recall that he is not merely h · *nu* but also and equally

$$\tfrac{1}{2} M_p \left\{\frac{1}{n^2} - \frac{1}{(n+r)^2}\right\}$$

As such, he will enter the atom by the same type of door as that through which he came out, and be peacefully transmuted from a "difference-tone" into two "terms" or "tones" *whose difference in energy is equal to what his energy was.*

In short, atoms *give* light of a definite wave-length and frequency represented by a definite line in the spectrum by *synthesizing* their internal and self-contained vibrations, "terms" or "tones" and emitting a "difference-tone." They *receive* light-waves by *analyzing* a "difference-tone" (when it can be so analyzed) into two of their own tones. Emission is a case of

$$\tfrac{1}{2} M_{p,\,q,\,w} \ldots \left\{\frac{1}{n^2} - \frac{1}{(n+r)^2}\right\}$$

becoming *h nu*. Reception is a case of this process reversed.

Let us conclude with some reflections upon atoms other than hydrogen, in the light of our theory of an atom as a sort of spiral spring constituted by the balance at a critical distance of two forces, a magnetic repulsion varying inversely as the third power and an electrostatic attraction varying inversely as the second power—these forces to obtain between and to originate from a positively charged and predominantly protonic nucleus that spins one way, and an oppositely situated negatively charged and exclusively electronic "planet" (or "planets") spinning the same way. By "oppositely situated" I mean, as previously stated, that a line joining the centers of the nucleus and any "planet" would be perpendicular (or more or less nearly perpendicular) to the planes of their respective rotations. The clumsy guardedness of the above statement is necessary to make the definition fit not merely the special and limitingly simple case of the hydrogen atom but the general class of cases exemplified by the other atoms, from helium to uranium.

With the protons and electrons acting alternately as a sort of cement for one another, various nuclear structures would be possible. The structure of the alpha-particle or helium nucleus seems to be the most stable; and for that reason it is an apparently universal element in all complex atomic nuclei. Such complex nuclei containing both electrons and protons might exemplify different directions of spin, but one of these directions would probably predominate. There would then be a critical distance for as many "planetary" electrons as were needed to make good the electronic deficit in the nucleus, which deficit defines the Atomic Number. The planetary electrons could not, however, all occupy the same position. They would push one another somewhat away and take their places on a shell or plane that was curved like the surface of a *parachute*. With respect to them the nuclear center would occupy a position analogous to that of the man hanging from the parachute. There might be several such shells, one beyond the other, and except in the case of hydrogen they would probably be located on both sides of the nucleus. The whole structure would thus resemble an *hourglass*. Between the nucleus and each of the outside electrons there would exist the same sort of spring-like balance of forces as we found in the hydrogen atom. "Tones" and the "difference-tones" that were emitted and absorbed would also exist in the same way. And each atom would thus have its series of spectral lines different from, but on the same generic plan as, that of hydrogen.

If the ordinary light-waves, together with the infra-red, the ultra-violet and

perhaps the x-rays, are to be accounted for by the vibrations passing between the nucleus and the outlying or so-called planetary electrons, what provision does our hypothesis make for those very short waves such as the gamma radiation which appears to have an exclusively intra-nuclear origin? So little is known about the detailed structure of the nucleus that even the most tentative answer to such a question may seem hardly worth while. We do know, however, that the protons are for some reason nearly two thousand times the mass of the electrons and we know also that there are no atoms with negative atomic numbers; in other words, every close-packed or nuclear configuration of protons and electrons contains an excess of the former. It may be that this excess of protons over electrons in the nucleus is due to the fact that the greater inertia of two protons would cause them to separate less rapidly in response to their electrostatic repulsion than a pair of equally repellent electrons, and that it would thus be easier for one electron to cement together two protons, as in the newly discovered isotope of hydrogen, or two electrons to bind together four protons as in the ubiquitous alpha-particle, than for a larger number of electrons to be cemented by a smaller number of protons. In any event, on our hypothesis of the protons and electrons as spinning and as being therefore not merely electrostatic but also magnetic, there would be spring-like balances of repulsion and attraction *within* the nucleus as well as *between* the nucleus and the outlying electrons. And from the vibrations within these purely intra-nuclear "springs" there might proceed as "difference-tones" the gamma rays and possibly even the cosmic rays.

Although the exigencies of recent Quantum theories have required the abandonment of the attractively simple model of the older Rutherford-Bohr atom, yet unless I am greatly mistaken the relatively unpicturable conceptions of the atom to-day involve in some form the original notion of the separate orbits (with their resulting separate energy-levels) in which the electrons revolve, giving forth their discrete bundles of radiant energy by jumping from one track to another. Now it was surely bad enough that the chemists should have been forced to abandon the static type of atom which as chemists they would naturally prefer, in favor of the dynamic type which physics appeared to necessitate. And when to that disadvantage there had to be added, by reason of the Quantum phenomena, the intolerably arbitrary conception of orbits, separated from one another like *grooves*, between which the electrons must choose with no possibility of intermediate paths, the burden upon belief became almost too great to be borne. Let us then remember that apart from the purely sentimental analogy with the solar system (which for all its unworthy irrelevance may not have been lacking in an unconscious psychological effectiveness) the only reason for making the outyling electrons revolve around their positively charged nucleus was to keep them from falling into it. If it is possible by such a hypothesis as I have advanced to explain through a balance of magnetic repulsion and electric attraction the existence of electrons held at arm's length from their nucleus without the necessity of preserving their distance by the centrifugal force of planetary revolution—is that not an advantage? And if the static atom can not only then be revived, but be revived in such a form that its discretely quantic radiation can be accounted for as the "difference-tones" or terminal interferences of the various waves which, like the tones and overtones of a musical string, would run to and fro over the

spring-like *field* connecting nucleus and electrons, is that not a further advantage of sufficient promise to extenuate the crime of a layman in venturing with amateur conceptions into regions where, until further facts are known, even experts fear to tread?

I conclude these highly speculative suggestions with four still more speculative corollaries in the form of queries.

(1) Is it not possible that the wave-like behavior of particles, not only electrons and protons, but even atoms and molecules, could be explained by their postulated spins which would undergo periodic retardation and acceleration on contact with obstructions such as screens and gratings?

(2) Is it not possible that the puzzlingly excessive radiation of the stars is caused by clashes between their intrinsically spinning corpuscles rather than (as is currently supposed) by a destruction of their mass through a suicidal proto-electronic amalgamation?

(3) Knowing as we do that alpha and beta particles are expelled with enormous velocities from the nuclei of radioactive atoms, is it not possible, and even probable, that these velocities have their source in a primal energy of spin on the part of the corpuscles composing the nucleus? For when rapidly rotating particles come in contact with one another part of their energy of rotation is changed into energy of translation. Contacts of this violently disruptive type might well be periodically recurrent and would certainly be more noticeably frequent in the massive, complicated and therefore presumably unstable nuclei of radium and uranium.

(4) If a light wave or squirm consisting of alternating twist-thrusts were to encounter an obstacle that would neither transmit nor reflect it, but simply stopped it from going forward, absorbing the energy of its thrust without impairing the energy of its twist, would not the wave then become a particle—electron or positron, according to its direction of twist, when stopped? Such particles would seem to differ from the waves from which they originated (and into which, when the circumstances were reversed they could return) only in this: that a twist which loses its forward thrust must continue its twisting and become a stationary spinning particle; while conversely a twist that acquired a thrust must spend itself by *inducing* a counter twist or twist-thrust directly in front of where it was, and so become an advancing wave.

AIR "FLIVVERS"

By Dr. EDWIN G. DEXTER

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THE question of cheap airplanes to meet a presumed popular demand has come prominently to the front, and a committee made up of outstanding leaders in American aeronautics, appointed at the authorization of the Secretary of Commerce, has met to study the problem of developing a $700 volume-produced airplane for private use—in other words, to place on the market an air "flivver." There is no reason seriously to doubt that under modern methods of mass production, it can be done, nor that in the no distant future, small but dependable planes can be bought at the price of the cheaper grades of automobile. But will there be a market for them?

Some time ago, the following appeared as an editorial in one of the leading papers of the country:

THE CITIZEN AND THE AIRPLANE

The failure of the public to patronize the airplane industry is no longer concealed. Americans are not becoming pilots in numbers sufficient to warrant the expectation that there will be a profitable business in selling airplanes to individuals for private use. Manufacturers have clung to the notion that the public would take up flying and thus create an industry comparable to the automobile industry; but in spite of reduction of prices and some improvement in the direction of safety, airplanes are a drug on the market.

The fact that Henry Ford explored the possibility of developing a market for small and cheap airplanes for private use, and did not find prospects worth while, is pretty good evidence that no such potential market exists at present.

Comment of a similar nature is more or less general.

What are the facts in support of such a contention?

Bleriot flew the English Channel in 1909—nearly twenty-five years ago. During the world war planes were doing about everything they do to-day except long-distance flying. In 1919 Alcock and Brown made a non-stop flight from Newfoundland to Ireland at a speed which has been but slightly exceeded since, and in the same year our Navy sent a plane across the Atlantic. That was nearly fifteen years ago. To-day transatlantic flights hardly make the front page. It takes a round-the-world journey or its equivalent in distance for a non-stop refueling flight to get headlines there.

More than one hundred and fifty round-trip flights are now being made daily by our commercial air lines within the continental United States with a daily average of 136,319 miles flown and carrying some 2,000 passengers at what would seem to be an almost negligible hazard. Mechanically the airplane has arrived, and no inconsiderable number of people are using it as a means of transportation. But the "flivver" is quite a different story. There seems to be little or no evidence that flying has taken any hold on the popular fancy as a means of diversion, or that planes are being generally used for other than utilitarian ends. Let us see.

The November 15, 1933, bulletin published by the Aeronautics Branch of the Department of Commerce lists 6,862 planes under the heading "Aircraft Licenses Active" and 2,314 under "Aircraft Unlicensed Active," making 9,176 heavier-than-air units—other than gliders—operable within the United States.

This does not include planes of the Army, Navy or Coast Guard.

These figures mean that there are in the country 9,176 planes used in commercial aviation or which are the property of individual owners and presumably used for pleasure. I have not been able to secure data which would show with any degree of exactness the number of planes belonging to the latter class; that is, pleasure planes, but an inspection of the ownership lists prepared by the Aeronautical Chamber of Commerce of the United States would seem to indicate that one in three would be a most generous estimate. If this be so, there are in the country at the present time roughly 3,000 planes of all descriptions bought for other than business purposes, and this number may be taken as in a sense a measure of the air-mindedness of the American people, as questioned in the editorial above given.

It is true of course that the 6,000 planes used strictly for commercial purposes, as well as some thousands owned by the Army, Navy and Coast Guard, have given airplane producers their principal support up to the present time, but the demand along these lines is and will continue to be limited and the real future of aviation is determined largely by the desire or the lack of desire on the part of the people to fly as they have driven their automobiles. The automobile industry has been prosperous, not because of the half million buses and trucks produced annually but because of the millions of pleasure cars sold.

The question then is: Do the roughly 3,000 planes, owned by individuals, and used presumably for other than commercial purposes, meet a reasonable expectancy, and do they give promise of a future for aviation in any way approximating that of the automobile?

A total of less than 10,000 planes registered at the end of the fifteen-year period since the Atlantic was spanned by air, with seemingly not more than 3,000 planes bought for other than gainful purposes, can not, even by the most enthusiastic aviation fan, be interpreted as evidence of a boom. One plane to some 12,000 inhabitants or, of privately owned planes, one to each 42,000 must be anything but encouraging to the producers.

Something seems to be wrong with aviation. What is it? It might be that production of planes has not kept up with demand and that potential buyers could not secure delivery. But on July 1, 1930, there were listed by the Department of Commerce 217 firms which were manufacturing planes on a commercial basis. They had produced 1,684 planes during the first six months of that year, or about seven planes each. I do not know how many of the firms listed in 1930 have since gone to the wall, but during the nine months from January 1 to October 1, 1933, 1,065 planes were produced, only 552 of which were listed as *civil* and *commercial*.

If, as is presumable, but one in three of these is for private use, it means that less than two hundred planes were purchased during that period for anything that might approximate "*flivver*" activities. It may, I think, safely be assumed that the firms were not back on their orders and that any person with the desire for a plane and the cash to back it up could have had such desire promptly gratified.

But how about the cost? Were it not for the fact that the American people have shown a determination to have what they want, irrespective of expense, the purchase price of a plane might well be considered a distinct setback to the popularization of aviation; in the last twelve years, however, they have spent some $30,000,000,000 for passenger automobiles, $3,000,000,000 for radios and $12,000,000,000 to go to the movies. There is money for what is wanted. Even during the lean year of 1933, more than 2,000,000 automobiles, including

trucks, were purchased at a cost exceeding $1,200,000,000. If one in fifty of these cars was in the $2,500 class, and it seems to me that would be a safe assumption, it would mean 40,000 such cars purchased. But dependable planes are on the market for less than that; and in nine months 552 were bought, most of which were for commercial purposes.

No, it is not the cost of planes that is the matter; nor presumably the cost of gasoline, since a small plane will make approximately as many miles on a gallon as will an automobile of approximately the same cost. We shall have to look further for a valid alibi for our aviation boom.

But a man can not keep his plane in the garage. Perhaps there's the rub. Again let us refer to the Department of Commerce Bulletin. On November 15, 1933, there were in the country 2,172 landing fields, no state being without one or more. Of these fields 556 are designated as "municipal," 656 as "commercial," 266 as "Department of Commerce, intermediate" and 540 as "marked auxiliary"; 627 have night-lighting equipment. I do not know how many golf courses there are in the country, but it would seem to me that flying fields must be about as available as they are, and very few addicted to the ancient and royal game seem to find distance an insurmountable obstacle to its enjoyment.

Maybe the trouble is in learning to fly: Inconvenience, cost, time required, difficulty and all that. Once more our good friend, the Department of Commerce. Three years ago it listed 283 schools of aviation situated in 234 cities and towns, with no state omitted except New Mexico. No one would have to go so very far from home, and the cost for the full course, including the use of planes for the required flying time, varied from $200 to $500; the time required from two to four months. These prices and time limits do not in all instances include ground instruction, but this is not required for the pilot's license. The cost then of learning to fly is roughly equivalent to that of a semester to a full year's tuition in a first-class medical or law school and the time required from one sixteenth to one sixth of the full medical or law course. The courses do not seem to have been overcrowded, judging from the total of 14,190 licensed pilots registered on November 15, 1933. This number is, by the way, 3,549 less than in 1931. I can think of no other element in the physical aspects of the aviation problem which may have militated against its successful solution.

There are plenty of people to make a market for planes; plenty of facilities for the production of them if wanted; plenty of schools for the training of pilots; plenty of air fields and seemingly plenty of money, if we are to judge by the expenditure for autos, radios, movies, etc. Yet people have not, in any considerable numbers, bought planes. The paltry 552 planes absorbed by our civilian population in the first nine months of the twenty-fifth year since Bleriot flew the English Channel is sufficient evidence of this. With the physical aspects of the problem exhausted there is nothing left but to turn to the psychological; and here I fear we have found the solution.

Airplanes take us into a third-space dimension which since man was man has penalized the intruder. As a result there has been developed a more or less general aversion toward getting far from terra firma. Long before Wright ever saw Kitty Hawk, psychologists had recognized the fact and had given it the Greek name Acrophobia. They have, it is true, placed it in the category of abnormal mental states—and therein lies our only hope for aviation, that it *be* abnormal—but the more I study the sub-

ject the more I am convinced that the feeling is so general as to place it among the normal instinctive repugnances.

Do we read with equal horror the account of a head-on collision between two planes high in the air, and one between two automobiles, the casualties being the same in each case?

Do the same tremors creep up our spines at the thought of Jones falling downstairs and breaking his neck, that do in contemplation of Linianthal's act of jumping from his plane, a mile high over the English Channel?

Are those people who feel ill at ease while gazing down from heights like those of the Empire Building, the Woolworth Building or the topnotches of a Ferris Wheel so few as to place them in the class of abnormals? Are those who shudder at the sight of a steeplejack, or a structural worker on a beam fifty stories up, normal or abnormal? Is the classic nightmare of falling through space an indication of mental aberration? Is the person who alights from the basket of a captive balloon after a thousand feet in the air, with a profound feeling of relief to be down, abnormal? I believe not. A frank confession would probably disclose the fact that most of us have those feelings, and that the fear of the abyss is a part of our emotional make-up.

Following the general arguments of the biologists, it should be, since the fundamental principle of evolution is "safety first," and in the long run it is safer to be down than up. Their explanation would be that somewhere far back in the development of the genus Homo and fully in accordance with the law of universal variation, there were certain individuals who loved terra firma and never budged from it, and at the same time certain others, who had no such feeling, but loved to climb and proceeded to get as high as they could, up trees, crags and whatever the landscape provided. None of the former fell and broke their necks, since for them there was nothing to fall from; so they lived till the end of the chapter, breeding progeny which, like their parents, were generally not climbers. Not so with the others. The hazard of height was a fatal handicap. Some of them crashed, and after a thousand generations more or less of elimination of the climbers and the survival of the non-climbers, we have few or very few of the former left.

Every instinctive act or aversion, whether of man or the lower animals, is explained by biologists in the same manner. For example: Far back in the evolution of the cat, some individuals liked to bask in the open spaces of the landscape, while others preferred the secluded spots around the edges. No one of them had figured out any advantage in either location. This primitive feline could not hold its own in a stand-up and knock-down fight with its jungle adversary. Its safety was in concealment or flight. In this, those individuals around the edges had the distinct advantage, and in the long run, more of them survived than of the others. Since like begets like, and the survivors possessed the edge-loitering characteristic, there has evolved the instinctive aversion, manifest in all small felines, to those spots which do not provide a well-covered and instantaneous retreat, that is, the wide spaces. Probably none knew why they evade them. But let any stray tabby come along, lacking the instinct, and the chances are that it will be eliminated in short order.

So it is with all instincts—a purely fortuitous origin, so far as we know, and a progressive selection for survival of those tending in the direction of the instinct. Generation after generation, this becomes more compelling; it can not be eliminated by any process of reason and can only be inhibited by a distinct and—in human beings—usually a distressing,

fiat of will. Instincts are, so to speak, nature's life preservers. They have determined almost entirely the behavior of the lower animals and, to a considerable extent, that of man in those fields which are common to him and his ancestors. There is no instinctive aversion to airplanes, since they were unknown to our forebears. There is none to high speed, such as we attain in our automobiles, since they could not by any possibility go fast enough to hurt themselves much. But they could get high enough to break their necks from falls. Hence, our instinctive love of terra firma. And do not make the error of supposing that this instinct is rational or that it is based upon any conscious evaluation of the hazard involved. Instinct and reason are at the opposite extremes of behaviorism.

I do not like you, Mr. Fell;
The reason why I can not tell.

Nor is it fear in the ordinary sense of the word. Flying is now relatively safe, hardly more dangerous than travel by train. People are not generally deterred by the danger involved. We know it is dangerous nowadays to cross a street, yet we cross it. A perusal of the data of accidents shows that it is dangerous to go upstairs, downstairs, to take a bath or to walk across a rug. Yet we do all these things without compunction, because we know the chance of accident is small, and we are willing to gamble on it. They are all dangerous, but not sufficiently so as to deter us. The drag in aviation is not, I believe, due to its danger as based on a conscious evaluation of the hazard.

It is my belief that the future of aviation is determined not by rational but by instinctive limitation; that its field is purely one of utility; that people as a class will not fly as a diversion, and that the only persistent flyers will be those who make their living by flying and those for whom it presents a financial advantage or meets an emergency which can not be ignored. Yet if this be true, it does not by any means relegate aviation to a back seat, except in comparison with the front seat hoped for.

The railroad, the motor bus and, to a large degree, the trolley come within the above stated limitations. Nobody rides on any of them, I take it, for the fun of it, unless it be occasionally on the last. And yet all are reasonably prosperous. But aviation, in competition with any of them, must present advantages which will overcome the inherent aversion, and that is no small handicap.

The hope that aviation will in any way simulate automobiling in its development is, I fear, a futile and an idle dream. It has shown no evidence of it so far, and it has had time. If one person a day uses each registered automobile merely for pleasure, there are 23,000,000 joy-riders each twenty-four hours; and 500,000 are estimated to have flown in 365 days; and I will wager that very few of them failed to have a distinct feeling of relief when their feet touched terra firma.

A man who had "barnstormed" with a plane for months once told me that in all his experience he had had but one repeater. It is my understanding too that a considerable proportion of the return tickets on round-trip excursions by air are never presented.

But, you ask, even though we accept this thesis of an instinctive aversion to getting far from terra firma, will not the next generation, born air-wise, so to speak, have lost it? There is nothing in the development of instinct that would lead us to believe so. Traits inbred through long generations can only be bred out in the same slow manner. I have a good old dog at home which has been a member of the family for more than a dozen years. I have had no difficulty in teaching him that beds and sofas and easy chairs are no place for him. Yet I have utterly failed to teach

him not to bark at the sound of a strange footstep on the stairs. Back, nobody knows how far, his ancestors barked at unfamiliar sounds; and that is why they were his ancestors. Those which did not failed to survive, since the noise either frightened the adversary or called the pack. My dog is not afraid of what the strange footsteps mean, but he can not inhibit the bark. No animal, human or other, ever tries harder to do what is expected of him than that dog, and he frequently comes to me with evident shame at the failure of his attempts to obey and be quiet; but there is still a little yelp which it is beyond his power to repress. It had taken him thousands of generations to learn that bark, and it will not be unlearned in another. And the same is true for anything learned by the same slow process.

We are, however, safe in assuming that human beings may be more successful in inhibiting the expression of an instinct than are the lower animals. Even though our instinctive aversion to heights exists, it does not mean that nobody will fly. It would not surprise me if nearly everybody did at least once, though there is little evidence so far that this is true. We like to prove to ourselves and to others that we are brave. Then there will always be the necessary personnel to man the ships, whether they be service or commercial; but they will no more fly for the fun of it than they do now, and most of them will be looking forward to the time when they can secure ground positions, as they are now. There will always be, moreover, a group, the size of which will be determined by conditions of the commercial air service, who will fly and continue to fly more or less indefinitely because the advantages of getting somewhere by the air route are so great as to lead them to overcome the instinctive aversion by fiat of will. But the emergency must be relatively great or the fare relatively small, to make this a sizable group. It would not be strange, too, if a limited number utterly lacked the aversion which we have postulated. This would be entirely in accord with the biological principle of universal variation underlying the development of instinctive aversions. But the sad feature of such atavistic tendencies is their immediate elimination. If the aversion followed nature's "safety-first" slogan, its lack has always meant the reverse with its consequent disastrous results. If those who, like the bird, feel perfectly at home and at ease in the air and who begrudge the time spent on terra firma could live long and breed fast, we might hope eventually to develop a race of bird-men; but such persons would tend to be the Icari of modern aviation and suffer the same fate.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

SEEDS

By Dr. J. T. BUCHHOLZ
PROFESSOR OF BOTANY, UNIVERSITY OF ILLINOIS

SEEDS are the most common device for reproduction among flowering plants. They are the only means of propagation for a large number of plants, including corn, wheat and other cereals, and for many of our garden vegetables and important timber trees, such as pines. However, many plants do not have seeds, and these are dependent upon spores or other means of reproduction. Ferns, mosses, mushrooms and pond scums are reproduced by means of spores, which are tiny rounded single cells that must begin to form a new plant after they are planted. Spores also make up the powder produced by a mould or mildew. A seed is much more complex than a spore. It consists of the embryo or minute baby plant enclosed in a seed coat. This embryo is made up of many thousands of living cells and is capable of resuming growth after a long or short period of dormancy and of becoming a plant similar to the one from which it came.

Thus we find the seed to be a sort of Rip Van Winkle episode in the experience of every seed plant. For several weeks or months, the embryo develops, usually reaching a stage in which it has one or two leaves, the beginning of a root and a tiny bud. Then this tiny plant inside the seed coat goes into a period of dormancy, which may last only a few days or weeks or, in other instances, many years.

The new plant, therefore, does not begin its existence when the seed is planted, but is formed long before this in the flower of the mother plant, which always precedes the formation of the fruit. It is obvious, therefore, that the seed does not die, as some people assume, in bringing forth new life; for the new plant is already formed and exists in miniature within the seed when the latter is planted.

If a seed is dissected by removing the seed coats, the embryo plant will be found inside, and it will possess practically all the parts which may be seen in a seedling on the day after germination. Take, for example, the seed of a radish or squash. This has, inside of the seed coat, an embryo plant with two seed leaves opposite each other, with a tiny bud between them, and below, the beginning of a root. The seed leaves and young root may be straight as in a squash or they may be folded and bent back on themselves within the seed coat in a great variety of ways. When this seed has germinated after planting, the two seed leaves unfold themselves and may be observed on the end of a little stalk, which is called a root, below the level where it penetrates the soil. The tiny bud, between the seed leaves, soon begins to grow rapidly and elongate into a leafy stem. Some seeds, such as the seeds of tulips and onions, have only a single slender or thread-like seed leaf with a bud placed along the side at the point where this single leaf may be considered as merging with the stem and root. While beans, radishes and squash seeds have only two parts, namely, the embryo and the seed coat, in many seeds the embryo is partially or wholly surrounded by a third part, a nutritional substance called endosperm.

It is this endosperm which furnishes

the bulk of the starchy food supply found in wheat, corn and other cereals. The endosperm serves as a sort of nurse bottle for the baby plant to last until it emerges from the seed coat. In the economy of the plant, it is the food intended for the embryo, but, alas for the new baby plant, it is also a source of food for animals and man. Aside from the foods obtained from potatoes and certain vegetables and roots, the large bulk of our starchy food supply comes from seeds, mostly from the endosperm, the food supply of the wee plant stored within the seed.

All seeds have endosperm in the early stages of development, just after the flower parts drop off. In the seeds of some plants a part of the endosperm remains much longer than this, but in others it is entirely consumed by the embryo before the seed is shed from the mother plant.

Whether the food is still stored in the endosperm of a ripe seed or has been consumed by the baby plant so that it is stored a second time within the embryo itself, as in the peanut, bean or walnut, this food supply does not spoil but is available as food for animal life. Thus we find that often the embryo stores its food in the form of oil or fat, the most concentrated form in which food may be stored. The Brazil nut is so oily that one may expose the interior at one end and burn it as a candle. Of course the embryo of a seed is also a source for protein foods. It is a well-known fact that beans and other legumes are one of our most economical or cheapest sources of protein food.

Although the seed coat is the dead part of the seed, it furnishes a very important protective covering for the embryo. It protects the embryo from excessive drying and mechanical injury, and keeps out disease germs. However, the seed coat admits abundant water and oxygen when the seed is planted. Most seeds may remain dormant within their seed coats for a number of years. Although all the mythical legends that viable seeds of wheat were obtained from the tombs and pyramids of Egypt have been disproved, the seeds of some plants have been known to remain dormant for more than a century and germinate very promptly when planted under suitable conditions. Thus a seed is a wonderful device, which may preserve a plant in a dormant condition over a long period of time.

Many so-called seeds are not naked seeds but are in reality fruits. The term fruit to the botanist does not necessarily refer to an edible part accompanying or bearing seeds. The fruit is usually that part of a flower which matures along with the seed, and often the fruit appears as nothing more than an extra layer or two surrounding the seed coat. A fruit may contain many seeds or only a single seed; it may split open to shed the seeds or it may remain closed and invest the true seed permanently with an extra protective layer. Sunflower seeds, acorns and other nuts, ranging in size from the small caraway seed to the coconut, are dry fruits not easily separated from the seed which they enclose. Naked seeds are illustrated by the poppy seed, the seeds of pine trees, of radishes, peas, beans, larkspur and cotton. The fibers of cotton are outgrowths of the surface of the seed coat and here the cotton boll is the fruit.

In size, seeds and one-seeded fruits range from the tiny orchid seeds, so small that many thousands of them would be required to weigh a gram, to the large double coconut or sea coconut, growing on the palms of the Seychelle Islands of the Indian Ocean. The latter, which may reach a weight of forty pounds, require about ten years to mature, from blossom to fruit. In addition to this, they require years to germinate when planted.

Fleshy fruits which do not split open usually shed their seeds in one way or another, though this may not happen before the fruit decays. Thus the melon contains hundreds of seeds, the persimmon and apple about a half dozen and the plum and cherry only one, from which the fleshy parts are eaten by man or beast, incidentally scattering the seeds widely. Many seeds which are eaten by animals have hard seed coats and, though they pass through the digestive tract without being digested, they remain viable and germinate afterward. This is an important means for the dispersal of these seeds and explains the mystery of how certain seeds are scattered widely by birds and migrating animals and why a pasture may become filled with strange weeds.

The mechanical methods of seed dispersal are so well known that we need mention only a few. Ocean currents carry coconuts from island to island. They also carry many other floating seeds whose covering is such that they are uninjured by salt water. Many seeds are small and carried by the wind, or they may be equipped with tufts of cotton or hairs such as are found on the seed of the milkweed or the common dandelion which afford small parachutes and help to carry them long distances in a gentle breeze. Even the squirrel contributes to the distribution of seeds when it hides its winter's supply of nuts and thus plants some of them in favorable situations. Some seeds or fruits adhere to the fur of animals and are distributed in this manner, while some heavier seeds are thrown out of the ripening seed capsule which springs open when the fruit is ripe. The seeds of some grasses and sedges are small enough to be carried on the feet of migrating water birds. For example, seeds of some of the rushes found at the water's edge are so tiny that there are about 70,000 to the gram. Other seeds, such as those of sedges, have air chambers which enable them to float on the surface of water and are distributed by wind and currents along the shores of lakes and rivers.

The story of the germination and development of seeds and seedlings is more or less familiar to every one who has planted and cared for a garden or window box. Sometimes people do not remember that the mechanism of reproduction has done its work within the flower which preceded the formation of the seed and that the new plant is already formed within the seed, ready to resume growth under favorable conditions, which we often help to provide when seeds are planted. However, in the economy of the plant itself the seed not only serves as a means of tiding over a long or short unfavorable period, but also as a means of multiplying the species many fold and of establishing a particular kind of plant in an infinite variety of new situations. Some plants which reproduce by seeds are so prolific that a single plant, as for example one of the wormwoods, has been known to bear over a million seeds. The jimson-weed is not unusually prolific, yet if all the seeds of a jimson-weed should germinate in a favorable place, a single plant one year could give rise to 15,000 plants in the next year. If these plants were properly spaced and each could again produce 15,000 seeds, it would require only 4 years to provide 500 times as many seeds as would be required to populate the entire earth's surface with jimson-weeds.

Thus perhaps one of the most remarkable things about seeds is the high yield possible per plant by which many species would be enabled to become world wide if they had an effective method of dispersal and were not the source of so great a part of our food supply.

THE INVISIBLE FRONTIER—OR FIVE MILES UNDERGROUND

By Dr. W. T. THOM
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But a single major frontier remains for the adventurous youth of to-day to penetrate and explore. The Old World and the New World are both known. The days of Daniel Boone and of Buffalo Bill are now but memories. The North Pole and the South Pole have both been reached, and darkest Africa is no longer a continent of mystery. Where, then, lie roads to a new El Dorado—to a land of new discoveries, and to a realm affording opportunities for men to prove their physical vigor, resourcefulness, skill and perseverance? Our new frontier lies beneath our feet, and our new quest is to learn what is within the earth as well as on it.

For many centuries people speculated as to what the realm of Pluto was like, or just how far down one had to dig to be in danger of a sudden plunge into the fires of hell. Such speculations were, however, without particularly important consequences, so far as can now be discovered.

Many of us have doubtless thought of what great depths had been reached when, a short time ago, oil operators actually drilled to more than two miles beneath the earth's surface, or when gold miners in South Africa penetrated for more than a mile and a half downward, but these depths shrink into insignificance when we compare the two miles thus penetrated, with the four thousand miles yet intervening between the bottom of the world's deepest oil well and the earth's center.

Geologists have indirectly penetrated deeper than the miner, and from the forms and relationships of surface features have deduced much as to the structure and constitution of the earth to a depth of about five miles. And now by a blending of geology and physics—developed partly from sound-ranging methods used for locating enemy cannon during the world war—we are engaged in a new campaign of underground exploration of what exists in the earth's sub-crustal mass, which will be at once scientifically important, educationally useful and practically worth while.

Why will such exploration be worth while? It will be worth while partly because it will add to the store of human knowledge; partly because it will give many red-blooded young men absorbingly interesting and satisfying work; and partly because it will in the course of time provide us all with a new knowledge of factors controlling the formation and place of concentration of ores as yet undiscovered, which civilization must have ere many decades, if it is to continue to supply itself with essential metals and mineral substances.

What methods of attack will be used in carrying out this exploration? Sub-crustal exploration will be carried out partly by the use of airplane photographs taken at great height, which reveal significant geological relationships invisible to one standing on the ground; partly by use of geological methods, which deduce from surface outcrops or from oil well or mine data what underground conditions are; and more and more by use of the so-called geophysical methods, which can be made to reveal underground conditions by careful studies of variations either in the local force of gravity; in earth conductivity of electricity; in earth conductivity of earthquake or explosion vibrations; or in the intensity of local magnetic fields.

By geologic interpretation of results thus obtained by applying physicists' methods and instruments to earth study, it is becoming possible for a geologist to learn of the earth's composition and anatomy, very much as an x-ray specialist now learns of the anatomy of one of his patients. True, the new geophysical arts are not yet fully developed, and their costs are yet high, but when one pauses to recall that by these methods it is now often possible to say that there is quite certainly a concealed oil structure beneath a particular square mile of a featureless alluvial plain hundreds of square miles in extent; or that a salt dome giving promise of oil and sulfur production exists beneath a particular lake, so many miles offshore in a given direction, and at a depth of so many feet; or that the thickness of sedimentary rocks filling a great trough-like downfold in the crystalline basement amounts to almost exactly 22,400 feet—we can realize what great progress has already been made in developing methods for penetrating the invisible depths of the earth.

What is the present state of our knowledge regarding earth composition? We know that many parts of the earth's surface are covered by a veneer of from a few feet to perhaps ten miles of layered sedimentary rock—most of which has been laid down in shallow sea water. We know that this outer film of sedimentary material rests on a basement of granite or of other crystalline rock formed either by the solidification of once-molten material or by the deformation and recrystallization of remotely ancient sediments. And we know that the earth apparently consists of a number of thick layers of rock, arranged much as are the layered coats of an onion, and that the rock materials composing these successive layers are progressively heavier and denser as the center of the earth is approached—the innermost core or centrosphere of the earth, some 1,500 miles in radius, being apparently composed of molten matter having the density of a nickel-iron alloy.

The best method of discovering the kind of material constituting the various shells of the earth is based on study of the speeds of the elastic waves made by artificial and natural earthquakes. From those speeds thickness of each shell can be measured with considerable accuracy. But to deduce the nature of the materials additional information is needed. We need to know how elastic are the principal kinds of rocks at the high pressures and temperatures prevailing in the earth's depths. This means special investigation of all the standard types of rocks when subjected to high pressure and high temperature simultaneously. Such a kind of research demands high technical skill. Further, any good deduction of the temperature of the earth's deep interior from the records of thermometers in mines and bore-holes similarly demands many laboratory experiments on the thermal conductivity of rocks at high pressure and temperature simultaneously—again no easy problem, but one being solved with modern methods. These and other fundamental experiments bearing on the subject are being carried on at the Carnegie Geophysical Laboratory at Washington and also under the direction of Professor Bridgman at Harvard University.

Other groups of workers in all continents have also been approaching the problem from another direction and have been seeking to advance, step by step, from the known surface of the ground to the unknown depths of the earth's interior, testing, proving and consolidating each gain in knowledge as it is made. And it is through a study of mountain structure and of how mountains grow that these other groups expect to learn definitely and accurately in

the relatively near future of the composition, properties and behavior of the outer, relatively strong and relatively brittle rocks of the earth's "crust," a "crust" which probably varies between ten and a hundred miles in thickness.

Geologic knowledge long ago progressed far enough to show that our world is far from being the *terra firma*, or stable earth, imagined by the ancients. A brief review of the geologic record shows that again and again mountain ranges and systems have been born, have grown to maturity and have then been gradually worn away by erosional processes. It is possible to point to featureless plains, in the outcrops of which the roots of primeval mountain ranges are visible; we can examine the old Appalachians which have almost wasted away under the attack of atmospheric agencies; we can study the more lofty and middle-aged Rocky Mountains, and can explore the still younger Alpine, Himalayan and Andean chains which are yet in the full stature of early maturity. Or we can watch the course of events in the great volcanic and earthquake belts girdling the Pacific, traversing part of the Mediterranean and circling the West Indian arc, in which infant mountain ranges are even now being born or are attaining their early growth.

In order that mountains may be formed, the outer film of the earth's surface—perhaps 5 to 20 miles thick, perhaps 50 to 100 miles thick—must be capable of sliding horizontally relative to points in the layers beneath. By determining the nature and amount of such relative sliding, it will be possible to ascertain not only how thick the moving film or veneer is, but also the mechanics of the movement, and, by induction, the nature of the forces which could possibly be productive of such deformations at periodic intervals.

Two lines of attack upon the secrets of mountain growth—and thus ultimately upon the problems of earth structure and constitution—give promise of being mutually supporting and highly successful.

One consists of a study of gravity conditions and bottom configuration in those parts of the oceans in which active mountain building is now in progress, for there the geometry of the growing sub-oceanic ranges can be ascertained free from modification by rain and stream erosion. Dr. F. E. Vening-Meinesz, of Holland, has pioneered in this study of sub-oceanic gravity conditions, in cooperation with the navies of the Netherlands, of Great Britain and of the United States—partly also with support from the Carnegie Institution and from the International Expedition to the West Indies recently sponsored by Princeton. And both government navies and surveys and merchant ships are supporting his work by making important contributions to our knowledge of the configuration of the sub-oceanic floor.

The second line of attack is advancing in the Alps and Scottish Highlands, in the Appalachians and Rockies, in the California Coast Range, in Japan and the East Indies, and in many other regions where erosional planation and canyon cutting make it possible to learn of the internal structure and deformational pattern of typical mountain ranges. Surface exposures in these regions make it possible to begin the reconstruction of the size, form and interrelationship of the individual uplifts composing a given mountain system, and underground evidence afforded by mines and oil wells will amplify this reconstruction and will in turn be further supplemented by the gravity studies of geodetic surveys and by other geophysical studies by oil and mining companies or by research organizations. Such researches will prospectively actually carry our pioneer study to "the

roots of the mountains," thus making possible the completion of a first main stage in our underground exploration.

How long a time this and subsequent exploratory stages will require no one can tell. What discoveries will be made either of new exploratory methods or of hidden oil and ore deposits, no one can guess. We know, however, that no such study has ever yet been made without important scientific, educational and commercial discoveries resulting therefrom; and, furthermore, we know of no other line of endeavor which holds out greater hope for adventure to those who would have joined in pioneering our American frontier had they been born a hundred years ago, but who arrived too late to take part in that epic of exploration and adventure.

NO ONE NEED HAVE SCARLET FEVER

By Dr. GLADYS H. DICK
THE JOHN McCORMICK INSTITUTE, CHICAGO

THIS talk concerns the possibility and the method of educating the body to protect itself against scarlet fever. No one need die of scarlet fever. No one need have scarlet fever. These statements sum up the results of two hundred and fifty years of intensive research on one of the oldest and one of the most dreaded diseases. The results are now available for protection of your children and of yourself against scarlet fever. The necessary materials can be obtained at your drug store, and your doctor can administer them.

Scarlet fever is caused by a minute microbe which can be seen only through a powerful microscope. Under the microscope, it looks like a minute chain of beads. The particular microbe which causes scarlet fever is characterized by its ability to manufacture strong poison. It is this poison manufactured by the scarlet fever germ which produces the symptoms peculiar to scarlet fever. And it is the discovery of the scarlet fever poison that has furnished us with the means of curing and preventing the disease.

Around a person who is suffering with scarlet fever, the air is contaminated with the patient's breath which carries minute droplets of moisture from the lungs, nose and throat of the patient. These droplets of moisture contain the scarlet fever microbes. They are so small and light that they float in the air for some time and may be carried to remote parts of the room by draughts.

If this contaminated air is breathed in by a well person, the microbe may lodge on the mucous membrane of the throat and nose. If the person who has thus become infected with scarlet fever germs has already had the disease, he usually remains well because his body has learned to protect itself. But so long as the scarlet fever microbes remain in his nose and throat, it is possible for him to pass them on to some one else without being sick himself. Such a person is known as a "carrier" of scarlet fever.

If the person who has breathed in the contaminated air has never had scarlet fever in any form, the microbes may grow in his throat and nose, producing the first symptom of scarlet fever, which is sore throat. Then as they grow in the throat, they manufacture their poison which is absorbed into the blood and carried to all parts of the body. Absorption of this poison causes the next symptoms of scarlet fever, nausea and vomiting. It also causes the scarlet red rash

which gives the disease its name. This rash usually begins to appear on the second day of illness, coming first on the chest and abdomen and spreading over the whole body, except the face. When fully developed, it consists of minute bright-red pin-point spots on a flushed skin.

If sore throat, vomiting, fever and rash exhausted the possibilities of scarlet fever, the disease would not cause much concern. In some cases, the patient grows rapidly worse and dies within a few days. In others the attack may be mild. But even the mildest attack of scarlet fever may be followed or accompanied by complications which may cause death or permanent disability. These complications most frequently involve the ears, kidneys and heart.

If the scarlet fever patient recovers from the disease, he does so because his body manufactures an antidote for the poison of the scarlet fever microbe. This antidote is known as scarlet fever antitoxin. If the body does not manufacture the antitoxin soon enough and in large enough quantities, the patient dies within a few days. But this antidote can now be manufactured artificially, so that it is no longer necessary to take a chance on the patient manufacturing his own. He can be given the artificially prepared antitoxin. If the scarlet fever antitoxin is given early enough and in large enough dosage, it cuts short the course of the disease and reduces the chances of complications.

However, the only sure way to prevent complications is to prevent the disease. This is possible. It is done by educating the body to protect itself against the scarlet fever germ through teaching it to manufacture the scarlet fever antitoxin or antidote. If a person has had scarlet fever and recovered, his body usually continues to manufacture scarlet fever antitoxin indefinitely, and this protects him against other attacks of the disease. But if one has not had an attack of scarlet fever, his body has not learned to protect itself, and if nothing is done to teach it, the body does not learn this lesson until it suffers an attack of scarlet fever, and an attack of scarlet fever is always accompanied by possibility of death or complications.

We now know how to teach the body to produce the antidote for scarlet fever which will protect not only against a fatal attack of the disease itself but also against all the complications of scarlet fever and against even the milder form of the disease. This is accomplished by five hypodermic injections of small, graduated doses of the toxin which has been freed from all germs either living or dead so there is no possibility of its causing damage. These injections are given under the skin on the upper arm at intervals of one week, requiring one month for all five. They stimulate the body to produce the antidote for scarlet fever, and this antidote which circulates in the blood protects the body from an attack of scarlet fever.

Persons whose bodies have thus been taught to protect themselves may mingle with scarlet fever patients and with carriers of scarlet fever without fear of contracting the disease. The protection thus conferred is quite permanent in the majority of cases, lasting for a period of at least several years and probably much longer.

Some bodies—like some minds—do not remember all they learn. About ten out of every hundred need to take a second course a year or two after the first course. They do not usually forget after the second series of lessons.

Not every one needs to be immunized against scarlet fever. In order to learn which individuals in a given group need to be protected and which ones do not need to be immunized, a skin test is made. This consists of the injection of

a minute amount of solution between the layers of the skin on the forearm to test for the presence of the scarlet fever antidote in the blood. If the person tested has enough scarlet fever antitoxin in his blood to protect him against an attack of the disease, no pink spot will develop at the site of the skin test. Such persons do not need to be immunized against scarlet fever. If a pink spot does develop at the site of the skin test, it indicates the absence of scarlet fever antitoxin from the blood and means that person needs to be protected against scarlet fever.

Briefly outlined the new methods for controlling scarlet fever consist of: (1) A skin test to learn which persons might contract the disease on exposure to it; (2) a course of hypodermic injections to educate the tissues of the body to manufacture the antidote for scarlet fever; (3) the prompt administration of artificially prepared antitoxin to persons who are already suffering from an attack of the disease.

These methods are new, but they are not experimental. They have been extensively and successfully employed in many thousands of persons in this and in other countries during the past ten years. Their safety and their efficacy have been established by these years of experience.

SPEED AND ITS SIGNIFICANCE IN CHEMISTRY

By Dr. HUGH S. TAYLOR
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An airplane flight from Key West to Havana is approximately the same distance as one from San Francisco to Reno, but the latter is a more difficult flight. This arises from the topography of the stretches which are covered. On the one hand, there is a swift, straight course over a level sea. On the other, the plane must gain the altitude necessary to cross the intervening Rocky Mountains, an effort which taxes to capacity the energy of the machine. The speed of the transit is correspondingly decreased. In the overland flight it is not necessary, however, that the plane attain the altitude of the tallest mountain peaks. Here and there, throughout the mountainous region, are passes, any one of which the aviator may choose to reach his objective with a minimum of altitude consistent with safety. Along such highways of the Sierras the planes pass and repass.

Chemical reactions result from collisions between individual chemical units or molecules. As these units approach one another they exert forces of a repulsive nature, which oppose the tendency to react. It is the speed of the approaching molecules which overcomes these repulsions and allows the molecules to get sufficiently close to one another that the constituent atoms may exchange or rearrange to form new substances. We may think of these repulsive forces in terms of the airplane flights which we have just been considering. When the repulsive forces are small, even small velocities of collision suffice to produce reaction; the energy required is relatively little, as in the overseas flight. When the repulsive forces are great, large "energies of activation," as they are called, are required. The energy of activation in such cases may be thought of as a mountain barrier of energy which the colliding molecules must overcome. As in the case of the airplane, the molecules can find, by myriad processes of trial and error, an energy mountain

pass through which they may approach each other, with the minimum consumption of energy, to attain their final state.

It is one of the triumphs of the new mechanics applied to chemistry that it has succeeded in calculating just what is the best mode of molecular approach and how high such energy barriers are, in terms of the forces operative between the molecules, thus permitting a theoretical calculation of the speeds of some of the simpler chemical processes. It is significant that such calculations have already been able to shed new light on the subject of speed in chemical processes and to point out cases in which our experimental facts were in error. All the text-books of chemistry indicate that fluorine is an element of high reactivity. Calculation showed that this was not strictly true, and recent experiment has confirmed the results of theoretical calculation. It has been shown that the speed of such reactions is in reality influenced by the walls of the container or by minute amounts of foreign materials and that great changes in reaction speed may be effected by such influences.

The ancient alchemist hurried his chemical processes by subjecting them to heat in alembics and crucibles. Even to-day, the commonest method of speeding up reactions is by raising their temperature. Heat increases the violence of molecular collisions and so the forces of repulsion are more frequently overcome. Other forms of energy may also be used. Nature, in the springtime, illustrates not only the effect of the warmer weather but also the accelerating action of light in the lengthening days of spring. Then occurs, with marvelous rapidity, that most arresting chemical change in which, from water vapor and the carbon dioxide of the air, there comes forth the loveliness of the daffodil, the swift growth of the peony bed. The intenser forms of energy, x-rays and the penetrating rays of radium, are also familiar, even to the man in the street, who knows of their use in accelerating the destruction of malignant growths in the human body. The electric current passing through solutions, electric discharges through gases and, latterly, high-speed, electrically charged particles moving under the influence of even millions of volts, these also are means whereby speed in chemical processes may be accomplished. Out of these last experiments a new chemistry is arising, a chemistry which has for its objective the shattering even of the atoms themselves. Speed in this achievement will give to the world atomic energy.

In the meantime, we must be well content with less spectacular though still arresting successes. The first quarter of the century has seen the perfection of the use of surfaces in speeding up processes of change. The chemist found that a process which would not occur in one stage because of the height of the energy barrier could be made to occur in several stages, each of which involved much smaller energy obstacles. The analogy of the zigzag pathway up the mountain face instead of the direct assault conveys something of the idea involved. Materials ordinarily regarded as inert, as, for example, nitrogen and hydrogen, react readily on iron surfaces at temperatures for which the reaction by collision alone is vanishingly small. This surface reaction alone has had revolutionary consequences for the whole world. It permitted Germany to wage a four-year war of unprecedented magnitude when cut off from the usual sources of fixed nitrogen, the niter beds of Chile. The same reaction, too, has, in the post-war era, vastly influenced the internal economy of Chile, formerly able to sustain all government enterprises on the revenue from saltpeter export taxes. All the great nations to-day fix the nitrogen of the air by surface reactions. The increases of speed thus

attainable are enormous. A reaction studied recently in the Princeton Chemical Laboratory was found to be accelerated ten million million million fold by a copper surface, and this represents a small, rather than a high, surface efficiency. The surfaces are efficient because, by reason of the unsaturation of the surface atoms, they are able to tear molecules apart into their constituent atoms, with small expenditures of energy, the atoms thus produced being able, with similar small energy effort, to rearrange to the new and desired species.

On occasion, also, the chemist can restrain the speed of chemical processes. He must do so in processes of conservation and preservation against deterioration. First-quality automobile tires are now expected to give a minimum service of ten thousand miles. The chemist has made that possible by finding how to compound with rubber minute amounts of chemicals which serve to arrest the normal tendency of rubber to perish. The development of ethyl gasoline, in which the addition of a few thimblefuls of what was once a rare organic chemical, ethyl lead, to gallons of gasoline entirely transforms the characteristics of the fuel—this is an instance of a suppression of an undesirable knock-producing explosive reaction harmful to engine cylinders. The introduction of rust-resisting steels is yet another instance of the chemist's ability in slowing down a naturally occurring undesirable process. In many of these processes the chemical changes occur in chains started by a single initial impulse, just as in a suitably ordered array of dominoes one falling domino will overturn the rest. The added agents are, in many of these cases, inhibitors of chain reactions. Rigid pegs placed between the rows of falling dominoes would illustrate their effect.

Let us return once more to the problem of atom disruption. Why is it difficult? Why is it a key problem of the future? It is difficult because of the inaccessibility of the nucleus of the atom which must be transformed. Each nucleus is surrounded by a potential energy barrier so high that heat and light are of no avail; only the swiftest moving particles, such as alpha particles or high-speed protons and neutrons, or else the most powerful energy units, such as cosmic rays, can pierce the energy barrier. Of itself, within its fortress of energy, it can not change and thus stays prisoner, save in those rare cases of the radioactive elements which spontaneously decompose. Here there is evidence that the departing fragment pierces rather than surmounts the barrier; it tunnels through just as the railroad engineer occasionally pierces the mountain rather than surmounts the surface altitude. It is a key problem of the future because he who finds the solution will find simultaneously rich and inexhaustible sources of energy. The energy arises from the annihilation of matter or from its transmutation to other forms of matter simpler in structure and less in mass. It is a problem which engrosses, however, not merely by reason of its material consequences, but also by its own intrinsic difficulty and beauty. This dual aspect of nature's problems is ever the lure of the scientific investigator. Its duality is finely expressed in those lines, by the late English poet laureate, Robert Bridges, from the "Testament of Beauty"—

> Science sitteth apart in her exile, attent
> on her other own invisibles; and working back
> to the atoms, she handleth their action to harness
> the gigantic forces of eternal motion,
> in serviceable obedience to man's mortal needs;
> and not to be interrupted nor call'd off her task,
> dreaming, amid the wonders of her sightly works
> thru' her infinitesimals to arrive at last
> at the unsearchable immensities of Goddes realm.

THE TELEPHONE POLE AND THE MUSHROOM

By Dr. R. H. COLLEY

OUTSIDE PLANT DEVELOPMENT, BELL TELEPHONE LABORATORIES

ACCORDING to the story, Alice had been running through the woods and had paused to rest near a large mushroom. Under the dramatic conditions of the experiment the mushroom was as tall as Alice herself. It may be assumed that she did not know it was a fungus. She probably had never heard of biology. But she was in a most unique position to get a proper perspective of that particular mushroom, and she proceeded to examine it from all sides. The umbrella-like top of the mushroom possessed very special powers. She found that a little bit taken from one side of it would make her grow tall, and that a little bit from the other side would make her grow short; and that by properly balancing the amounts of each piece she could keep herself just about the right size. It is small wonder, under the circumstances, that the mushroom assumed such a large though temporary importance in Alice's eyes.

Outside of the fable such opportunities for gathering information about fungi are likely to be confined to the realms of the imagination. Formerly the evanescent fairy rings of toadstools in moonlit meadows were the arenas for the sports and games of elves and gnomes and dwarfs. Nowadays these same fairy rings form their strange circles in the grass to spoil the turf on putting greens. The fact that mushrooms appear for a time and then are gone gives them a sort of will-o'-the-wisp character. They are, however, very real.

If, for convenience, all plants be divided into two groups—those having the green coloring matter called chlorophyll, on the one hand, and those that do not have it, on the other—we may define the position of the fungi by saying that they belong to the latter group. The two groups are continually in opposition. With the aid of chlorophyll and light, and the substances found in air, water and soil, the green plants make and store up a food supply. Green plants are builders. Fungi, generally speaking, are destroyers or scavengers. Lacking chlorophyll, they are dependent for their food supply on the tissues and stored substances made by the green plants. They are often classed, therefore, either as parasites or saprophytes, depending respectively on whether they attack living plants or simply break down the non-living product of the green plants. The forms of fungi are myriad, varying all the way from minute, single-celled organisms, to giant shelf-like brackets. The latter belong in the great group which includes the mushrooms and their relatives, and it is this group which is of special interest to those concerned with outside plant.

Certain mushrooms and many forms of bracket fungi are the most important wood destroyers in the world, probably not excepting fire and man. After a tree reaches a certain age it becomes more and more susceptible to infection by such fungi. They attack any exposed sapwood, and they gain entrance to the heartwood through wounds or along old branch stubs. Once established, they proceed slowly but surely to turn the wood back into the elements from which it was created. Other fungi, usually

distinct as far as species is concerned from those that attack the wood of the living tree, are lying in wait to attack the wood of the tree as soon as it is sawed into lumber or cut and peeled for use as a pole.

Given a potential food supply, such as the sapwood of southern pine, there must be a sufficient amount of moisture present, and a sufficient amount of warmth, before the fungus can attack the wood at all; and the warmth and moisture conditions thereafter determine largely the rate of growth and the degree of destruction. Of the two factors, moisture and warmth, moisture is the more important. For instance, thoroughly wet or thoroughly dry wood will not rot. There is too much moisture in the one case, and too little in the other. Cold slows down or stops fungus activity, but low temperatures rarely kill. Favorable growth temperatures range generally between 70° and 100° Fahrenheit. Higher temperatures retard the growth, and more intense heat kills the organism. Moist heat kills more quickly than dry heat.

With this background of generalities, a more specific description of the fungus life cycle may be introduced. The simplest unit in this life cycle is a single cell, or spore, that corresponds by analogy to the seed of green plants. The spore germinates, if the moisture conditions are favorable, by sending out one or more delicate germ tubes. Germination may be said to correspond to the sprouting of the seed. If germination has taken place on the ground the germ tubes lengthened out into filaments that branch and rebranch among the soil particles. Food is probably obtained by absorption from the material in solution in the soil water or by direct attack on plant debris in the soil. If a spore happens to be blown into a check in the surface of a pole, or if it is drawn into the check by capillarity, germination may take place under conditions that make it possible for the germ tube to find its way into the cells of the wood. If there is enough water in the wood, say 25 or more per cent., based on the oven dry weight of the wood, the germ tube develops into a branching system

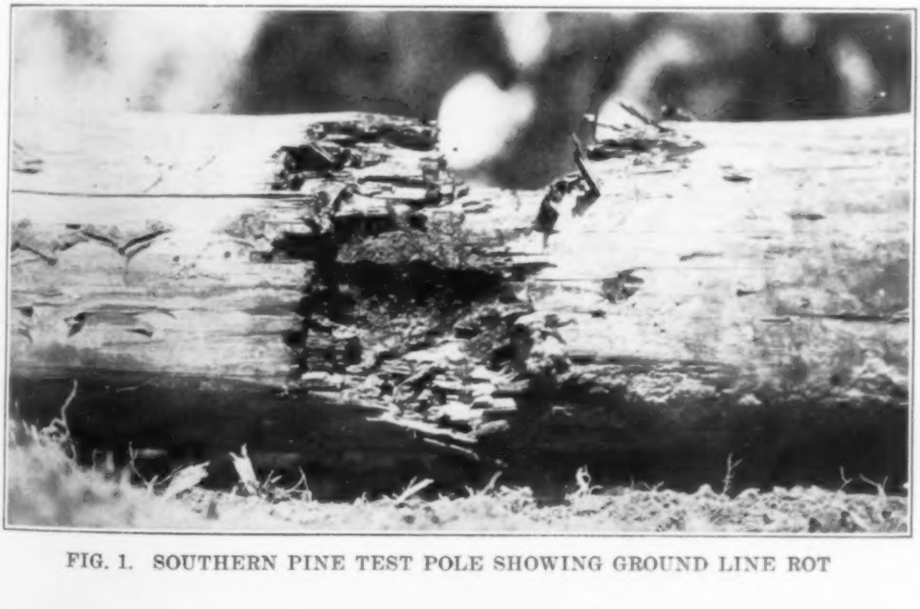


FIG. 1. SOUTHERN PINE TEST POLE SHOWING GROUND LINE ROT

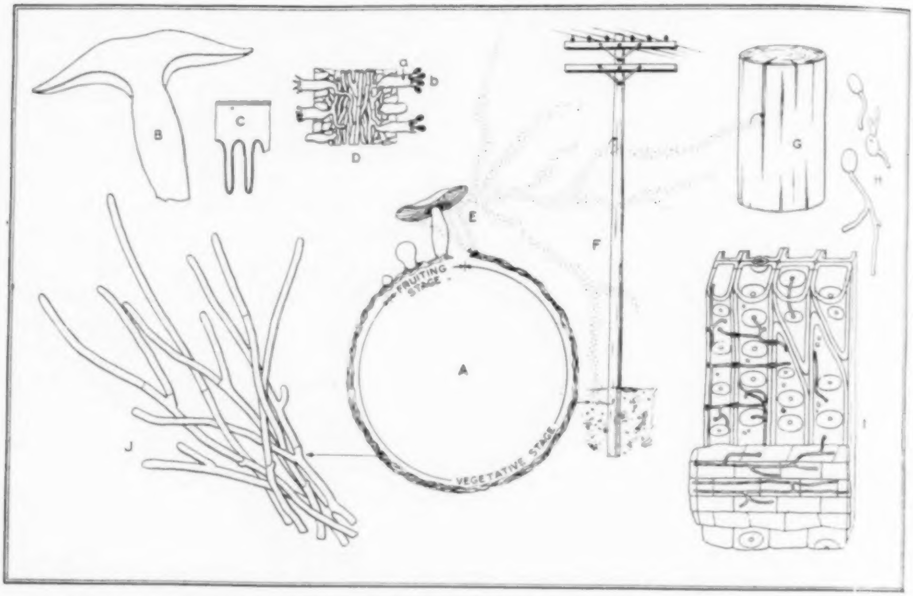


FIG. 2. MUSHROOM AND MAINTENANCE—A MURAL IN MINIATURE

A. The life cycle of the mushroom is made up of two alternating stages, an indefinite vegetative stage and a relatively short-lived fruiting stage. In the course of the cycle the fungus filaments (mycelium) mass together and from the tangle the full-sized mushroom develops. B. A longitudinal vertical section of the mushroom. Thin plates called gills hang from the under surface of the cap. C. The surfaces of the gills are covered with stubby cells that bear the spores. D. An enlarged view of a part of one of the gills showing the spore-bearing cells (*a*), and the spores (*b*). E, F, G. The spores ripen on the gills and are then carried by the wind to the ground or to some likely resting place such as a check in the pole G. The checks in the surface of the pole G serve as ports of entrance to the inner sapwood and the heartwood of the pole. H. Germinating spores. The germ tubes develop into filaments that either spread through the soil and into the below-ground section of pole F, or infect the upper part of the pole directly through a check. I. A diagrammatic representation of a mycelium of the fungus working its way through the wood cells. Compare Fig. 5. J. The tip of an advancing mycelium fan. Compare Fig. 3.

of fungus filaments (mycelium). At first the growth of these filaments depends upon the reserve food material in the spore. Then, as they become longer and longer, they bore through the wood cells and begin to destroy the cell walls.

These walls are laminated structures made up of cellulose and lignin. Just how the fungus breaks down these substances is not clearly understood. It seems probable that enzymes are produced locally at the tips of the filaments and that these enzymes soften the walls so that the filaments can bore through from one cell to another. The destruction process suggests a catalysis. In the advanced stages of decay the cell structure of the wood becomes more or less completely disintegrated.

The wood in that part of a pole in contact with the ground probably becomes infected by fungus filaments that are present in the soil. Above ground

the infection appears to result from the germination of spores carried by the wind, by rain-water, by birds and animals and by insects.

All the time the fungus is in the filamentous form, and while it is actually breaking down or rotting the wood, it is said to be in the vegetative stage. After the rot has become well advanced the filaments may or may not mass together. If they do, and the moisture conditions are still favorable, a pronounced change in the behavior of the filaments takes place. They merge into a tangled mass; and instead of remaining microscopic threads, hidden away from the light, they begin to work to the outside of the pole. From the massed filaments a typical mushroom may appear overnight, to remain for a short time before it is eaten by insects, or before it dries and is blown away by the wind. Before it is destroyed, however, it produces millions of spores, a few of which may in their turn, if the conditions are right, germinate and start another revolution of the life cycle.

There is a marked difference in the virulence of wood-destroying fungi. A few appear to be omnivorous. Others are limited to certain woods. Generally speaking, the fungi that attack chestnut, or cedar, will not attack pine, and the common fungi on pine will not attack chestnut and cedar. There are exceptions to the general rule. The woods themselves vary in their natural resistance to attack. The sapwood of all species is non-durable. The heartwood, on the other hand, is relatively durable. The heartwood of the cedars is among the most durable of woods; the heartwood of chestnut ranks high for durability among the woods of broadleaf trees; and the heartwoods of southern pine and Douglas fir are fairly durable if they are kept from contact with infected sapwood.

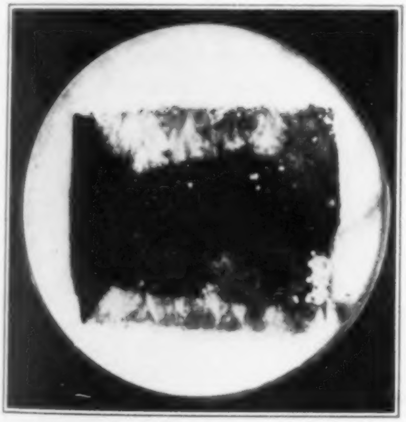


FIG. 3. IN THIS CULTURE, A WOOD-DESTROYING FUNGUS IS GROWING ON AN AGAR JELLY, ON TOP OF WHICH IS PLACED A THIN SLAB OF WOOD. THE MYCELIUM OF THE FUNGUS IS SPREADING IN FAN-LIKE WEFTS OVER THE SURFACE OF THE WOOD.

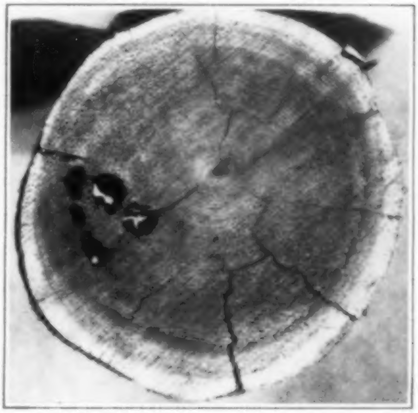


FIG. 4. LOCALIZED "PIPE ROT" IS HERE SHOWN IN THE HEARTWOOD OF A NORTHERN WHITE CEDAR POLE. SIMILAR LOCALIZED ROTS OCCUR IN CYPRESS AND REDWOOD. THEY RARELY SPREAD AFTER THE TREE IS FELLED.

It so happens that the cedars and chestnut have a relatively thin sapwood layer surrounding the durable heartwood. The depth of this layer in chestnut averages only about .22 inch; in western red cedar it averages approximately .65, and in northern white cedar approximately .55 inch. In Douglas fir the sapwood on pole size timber is a

little more than twice as thick as the sapwood of western cedar. Lodgepole pine sapwood has about the same thickness as Douglas fir. The sapwood of southern pine poles averages about 3.2 inches deep. It may be assumed that this sapwood is a most easily available food supply for fungi. This is another way of saying that the sapwood is soon attacked and destroyed under conditions favorable to fungus growth. Infection may take place while the poles are lying in the woods or in storage piles in yards of the pole producers. In fact, infection is so general that it may be regarded as inevitable unless certain precautions are taken. These precautions are usually aimed at controlling the moisture conditions, and that amounts to getting the water out of the sapwood as soon as it is practicable to do so. The faster the sapwood dries the less chance there is of infection; and if the wood is once dried and then kept dry it is not likely to rot, because the moisture content is too low to promote fungus growth.

FIG. 5. THIS SECTION OF AN INFECTED PIECE OF SOUTHERN PINE WOOD, CUT IN A RADIAL PLANE, SHOWS THE TUBULAR WOOD CELLS THAT RAN LENGTHWISE IN THE TREE (*a*), A PATCH OF RAY CELLS (*b*) THAT RAN RADIALLY FROM PITH TO BARK, AND THE FILAMENTS OF THE ATTACKING FUNGUS (C). THE ELLIPTICAL BODIES IN THE WOOD CELLS (D) ARE BORDERED PITS, OR OPENINGS, THAT LEAD FROM ONE CELL TO ANOTHER.

FIG. 6. CHESTNUT POLES OCCASIONALLY ROT ACROSS THE WHOLE DIAMETER. ROTS OF THIS TYPE CAN NOT BE CONTROLLED BY TREATING THE BUTTS OF THE POLES WITH CREOSOTE BECAUSE THE INFECTION WORKS FROM THE INSIDE OUT.

All things considered, it would appear to be easier to dry out the thin sapwood of the cedars and chestnut than to dry out the sapwood of southern pine, and

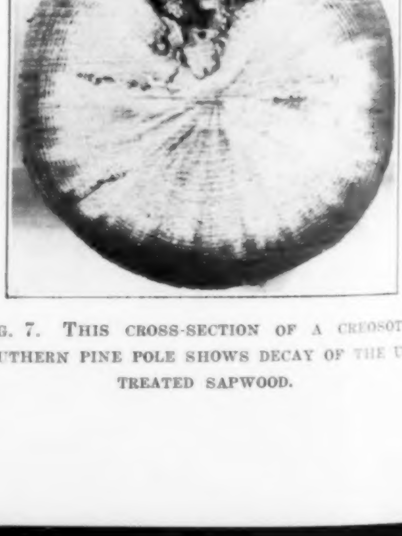


FIG. 7. THIS CROSS-SECTION OF A CREOSOTED SOUTHERN PINE POLE SHOWS DECAY OF THE UNTREATED SAPWOOD.

generally that is the case. However, if a dry pole is placed in the ground two sets of moisture conditions arise. The sapwood on the part of the pole above ground becomes alternately wet and dry, according to the weather conditions, while the sapwood on the part of the pole below the ground is kept moist by water in the soil. For a time the sapwood in the upper part of the pole may be resistant to fungus attack because of its relative dryness, but the moisture and food supply requirements of the fungus are met in almost ideal fashion in the sapwood below ground. Except when the ground is frozen or in the cold weather of spring and fall, the temperature conditions are favorable for growth. The result is a fairly rapid disintegration of the moist sapwood. Obviously, the pole user, in his fight against decay, can not depend on controlling moisture content. There is only one other way to handle the situation and that is to poison the food supply. So it appears that as far as fungi are concerned a relatively simple biological fact is the basis of the wood-preserving industry, whose business it is to make wood unpalatable to fungi.

The most commonly used wood preservative is coal tar creosote. Durable woods like cedar and chestnut are butt-treated by soaking the butt ends of the poles, up to about one foot above the ground line, in creosote. Lodgepole pine for use in the relatively dry mountain states is also butt-treated because the sapwood on the part of the pole above ground does not hold enough moisture to satisfy the water requirements of wood-destroying fungi. Southern pine and Douglas fir are treated full length by impregnation with hot creosote under pressure, the purpose being to penetrate as much of the sapwood as practicable.

Such preservative treatments are absolutely necessary if the poles are to give long service in the lines, all because, in nature's scheme of things, certain non-green plants called fungi are continually tearing down the wooden products made by the activities of the cells of certain green plants called trees. Man interferes in the biological battle, but his best efforts result in merely deferring the victory by the persistent cobwebby filaments of the fungus.

Alice's adventure with the mushroom seems not so wonderful, after all.

WILLIAM MORRIS DAVIS

THE PROGRESS OF SCIENCE

WILLIAM MORRIS DAVIS, AN APPRECIATION

To but few men is it given to enjoy vigorous activity in a field of science continuously for a span of six and a half decades and to be, moreover, the outstanding and acknowledged leader in that field for a large part of that period. Yet such was the enviable experience and admirable accomplishment of William Morris Davis, physiographer and geologist, whose long and rich life ended rather suddenly but peacefully at Pasadena, California, on February 5 of this year. He had not quite reached his eighty-fourth birthday.

Of the scientific men of this country, Professor Davis had been for many years one of the best known, not only to workers in the geological and other sciences but also to the general public. Of his voluminous writings many were couched in a style and terminology which rendered them comprehensible to the non-technical reader as well as highly instructive to the specialist.

The studies of his earlier years were largely of more strictly geological nature, some of them in the tilted and eroded formations of the Connecticut Valley, and these gave an excellent foundation for his later work. The much more important and really great fundamental contributions were mainly in the physiographic field, or geomorphology, as that branch of geology has been termed in later years. It was known still earlier as physical geography. Professor Davis often considered himself a geographer, but it was not with the regional or the economic phases of geography that he was concerned, or the adaptation of man to his environment, which so largely absorbs many geographers to-day. He was interested chiefly in gaining a more precise understanding of the nature of the land forms of the earth's surface, the origin of those surface features and the later geological history which can be deciphered from them when they are carefully studied. Naturally one of the important results of his work was a fuller comprehension and appreciation of the character and origin of natural scenery.

He began his scientific career shortly after the publication of the "Origin of Species," and he more than any one else in this country urged that the evolutionary concept is as applicable to the origin of the physiographic features of the earth's surface as to the organic kingdom. According to this view, the landscapes of the globe have not always existed as we now see them, nor were they so created; instead, they are the result of evolution through a long series of orderly changes.

Professor Davis' scientific papers are characterized by clarity, unusual completeness of statement, inclusion of vast detail in support of the general thesis advanced and by remarkable illustrations, in large part freehand drawings of high effectiveness executed by his own hand.

Space forbids mention of all the subjects which he investigated, but among the more important were the geographic cycle or cycle of erosion, coral reefs, glacial sculpture, the ranges of the Great Basin, the influence of geologic structure on topography, marine shore terraces, river terraces, the unique land forms produced and the precise processes involved in desert erosion.

The concept of the cycle of erosion, so magnificently elaborated by him and taught to the geological profession with unabated vigor for several decades, influenced physiographic thinking profoundly. It is this concept with which

Professor Davis' name probably is linked more closely than with any other in the minds of American and European geologists and geographers. Briefly, it postulates that when a region is uplifted from low to high elevation it is attacked and dissected by streams and other erosional agencies and passes through a cycle or orderly series of systematic topographic changes whereby it is in the end again worn down to the rather flat landscape at low level which it possessed before uplift. Davis termed the successive stages in the cycle youth, maturity and old age, and described fully and with remarkable vividness the physiographic characteristics of the landscape in each stage. These characteristics, once known, can now of course be used to ascertain whether an area has been uplifted relatively recently, a somewhat longer time ago or at a date much more remote in geological time—but never very remote, since it is recognized that the whole cycle requires only a small fraction of the total length of geologic time for its completion. The landscape of a region in youth—recently uplifted—is marked by bold canyons, large areas of original pre-uplift surface as yet unmodified and undissected by the headward-growing streams which will soon invade it, high gradient and swiftness of the streams and coarseness or gravelly character of their burden, and close resemblance of the uplifted area to the form determined by the nature of the uplift, whether an upwarped arch or dome, upwarped or upfaulted plateau or tilted fault block. In maturity the whole region has been dissected to slopes, the relief within it is at a maximum, the streams have begun to widen the downstream parts of their valleys by lateral corrasion and now carry much more fine material, and all remnants of the pre-uplift topography have disappeared. In old age the region has been worn well down toward its pre-uplift elevation, the mountainous relief of maturity has melted down to one of hilly or rolling aspect, the streams are slow and wide and carry mainly clay, and deep soils, giving rounded contours to the countryside, rather than extensive rock outcrops, characterize the landscape. And in very advanced old age the area becomes a "peneplain," a rather featureless "almost plain" on which the only eminences consist of residual hills of somewhat harder rock as yet not entirely reduced by the prolonged erosional process. The erosion cycle has become extremely useful to geologists in the elucidation of the later geologic history of areas under investigation and to travelers generally as an aid in understanding the landscape.

A unique feature of Professor Davis' scientific work, particularly on the erosion cycle, was the use of what he termed the deductive method. This consisted first of the formulation, with the aid of facts already discovered, of an explanation or hypothesis for the particular phenomenon or problem; this explanation was often elaborately developed by logical reasoning rather than by observation. Then with the postulated explanation as a guide, not for searching for certain facts favorable to it but for pointing out the type of evidence that would be critical, further observations would be made. The explanation would then be tested by confrontation with these additional facts.

The problem of coral reefs and atolls held Professor Davis' interest for many years. Quite recently he published a book supporting strongly and elaborating the view announced by Charles Darwin that barrier reefs and atolls develop from fringing reefs through subsidence of the islands on which they rest, and setting forth fully the relation of the physiographic history of islands to the character of the reefs encircling them.

Graduating from Harvard in 1869, he served as professor from 1877 to his retirement in 1912. Beginning about 1924, he lectured at universities in Cali-

fornia, Oregon and Arizona and during the past three years was a member of the staff at the California Institute of Technology.

He was greatly interested in teaching methods and devices. A set of illustrative models he designed, depicting natural features ranging from volcanoes to glaciated peaks, were scattered widely in the schools of the United States. With advanced students, especially, his enormous enthusiasm was very inspiring.

Organizing scientific parties was a joy to him. In 1912 he led the Transcontinental Excursion of the American Geographical Society, in which many scholars from abroad participated. During the last decade of his life he was largely instrumental in organizing two scientific outdoor clubs in southern California—the Rift Club and the Southern California Intercollegiate Excursions.

He was the author of a number of important books, mainly in the field of physiography, in addition to the large number of shorter scientific contributions in the journals. Great interest in the application of scientific knowledge to the betterment of society led to the publication of several introspective essays bearing on sociology and ethics.

He had traveled extensively in practically all the continents and was at different times exchange or visiting professor at several of the great seats of learning in Europe.

To the end of his life his lectures, both popular and technical, delighted his hearers. The illustrated lecture on the Grand Canyon, delivered before audiences in all parts of the United States, became virtually a classic and was enjoyed by thousands of persons.

Born of Quaker ancestry, Professor Davis made the world in which he spent his life a better place for humanity—scientifically, socially, morally.

JOHN P. BUWALDA,
Chairman, Division of Geology and Paleontology
CALIFORNIA INSTITUTE
OF TECHNOLOGY

THE AWARD OF THE WILLARD GIBBS MEDAL TO DR. UREY

FOR his discovery of "heavy water," which promises to rank among the great achievements of science, Dr. Harold Clayton Urey, of Columbia University, has been awarded the Willard Gibbs Medal of the Chicago Section of the American Chemical Society.

Dr. Urey was born in Walkerton, Ind., on April 29, 1893, the son of Samuel Clayton Urey and Cora Rebecca Reinoehl. His father, who was a minister and a high-school teacher, died when he was six years of age, leaving also a younger brother and a sister. The widow, in spite of severe financial handicaps, was determined that her son should receive an education, and it is due to her heroic efforts and the later help of his step-father, M. A. Long, that he received a college education.

The medalist's summers were spent working on the farm until he was eighteen years of age. During the winter he attended the Walkerton and Kendallville, Ind., high schools. In 1911 the family moved to Montana, and after teaching country school for three years, he entered the State University of Montana at Missoula, receiving in 1917 the B.S. degree in zoology. During the war he was employed as a chemist with the Barrett Company at Philadelphia.

Following two years' service as instructor in chemistry at Montana, he adopted Horace Greeley's advice and migrated to the University of California at Berkeley, where he came under the inspiring influence of G. N. Lewis. He was assigned the problem of verifying experimentally the predictions of the Sackur-Tetrode equation applied to the thermal ionization of cesium vapor, but

Ossip Garber Studio.
DR. HAROLD CLAYTON UREY

did not succeed in this objective. Fortunately this problem focused his attention on Bohr's theory of atomic structure, which at that time had not been sufficiently appreciated by chemists in this country. He presented a theoretical thesis on the calculation of the heat capacities and entropies of gases. This appears to have been the first application in this country of the accurate data obtained from band spectra to fundamental thermodynamic problems. The science of statistical mechanics is indebted to Professor Urey for his courage in breaking new ground in a field which has since developed into an important chapter of modern physical chemistry.

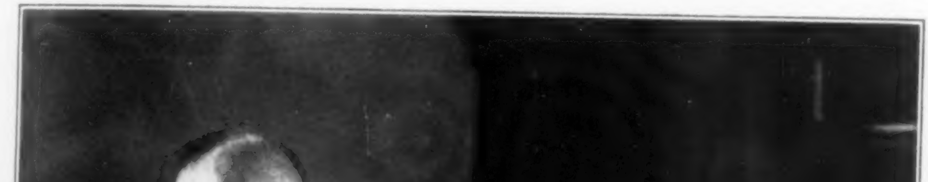
Professor Urey's interest in atomic structure received encouragement by the award of the American Scandinavian Foundation Fellowship for study at Copenhagen under Niels Bohr. The year 1923–24 was a most fortunate time to be in Bohr's laboratory. It was one of those periods in the history of atomic physics when the attack upon an apparently simple problem uncovered fundamental problems more rapidly than they

could be solved, when the problems themselves often proved to be incapable of solution by the means then available, a time when even the first law of thermodynamics seemed of doubtful validity in the light of the observed phenomena. He had the good fortune to be associated in these enterprises with a number of young men who were then making lasting international reputations in physics, among others, H. A. Kramers, Werner Heisenberg, W. Pauli and J. C. Slater.

His training as a chemist at California and his experience in physics at Copenhagen determined his present work in the border line between chemistry and physics, as is evidenced by his editorship of the *Journal of Chemical Physics* and many publications culminating in the treatise published in 1930 with Professor A. E. Ruark and entitled, "Atoms, Molecules and Quanta." This book has become an outstanding work on atomic and molecular structure in English.

On returning from Copenhagen he was appointed associate in chemistry at the Johns Hopkins University, and in February, 1929, he joined the department of chemistry of Columbia University for the purpose of developing the fields of atomic and molecular structure.

One of Professor Urey's distinguishing characteristics is his interest in somewhat unorthodox researches. His greatest pleasure comes in attempting problems which often have the hazard of giving negative conclusions but which at the same time hold out the possibility of giving novel results. The year 1930–31 was thus spent in an unsuccessful attempt to separate the isotopes of chlorine by photochemical means. Early in



EDWARD WIGHT WASHBURN

CHIEF CHEMIST OF THE NATIONAL BUREAU OF STANDARDS UNTIL HIS DEATH ON FEBRUARY 6.

the summer of 1931, Professor Urey became convinced on several grounds that an isotope of hydrogen of mass two should exist, and that it should be possible to prove its existence if proper precautions were taken in producing and photographing the spectrum of the hydrogen discharge tube. Here was a problem that certainly appeared to be destined for negative results, as this spectrum had been carefully studied by many investigators. Through the cooperation of Dr. Brickwedde, of the cryogenic laboratory of the Bureau of Standards, samples of liquid hydrogen, which had been redistilled under conditions suspected on well-founded principles of favoring the concentration of the heavy isotope, were tested in the discharge tube with the assistance of Dr. G. M. Murphy. The essential precaution taken was that of accentuating the atomic spectrum and depressing the molecular spectrum by the addition of water vapor, which effectively prevents the recombination of hydrogen atoms on the walls of the tube. This time the goddess of good fortune favored the research, but the favor was overdue and well deserved. The discovery was made possible only as a result of intelligent planning based upon sound theoretical principles.

Dr. Urey early suggested to the writer and his colleagues the possibility of separating the isotope by electrolysis, but in view of the numerous failures in the case of other elements and the lack at that time of any plausible theoretical reason for success, we had to forego the experiments in favor of the method of gaseous diffusion, which had yielded encouraging results through the partial separations of the isotopes of other elements. Shortly thereafter Dr. E. W. Washburn, of the Bureau of Standards, submitted for spectroscopic analysis samples of water exhibiting densities greater than normal which he had prepared by electrolysis.

It is a matter of deepest regret that Dr. Washburn's untimely death on February 6, at the age of 52 years, occurred before he had received the recognition which he so richly deserved for discovering the remarkably effective electrolytic method of preparing "heavy water," the more so when it is recognized that he prosecuted his researches not only in the face of declining health, which was both rapid and certain, but also in spite of drastic and discouraging reductions in the budgets of the scientific bureaus of the government for work of this character.

Urey's discovery of the element and Washburn's method of separation have revolutionized the research programs of many laboratories in chemistry, physics and biology. The reason is quite evident. Hydrogen as the constituent of water and in the form of numerous carbon hydrogen compounds is the element most frequently encountered by the chemist and biologist. The physicist is intensely interested in the use of the deuterium nucleus, or so-called deuton, since he has found that it has remarkable properties as a projectile for producing transmutations of elements and particularly for the production of neutrons.

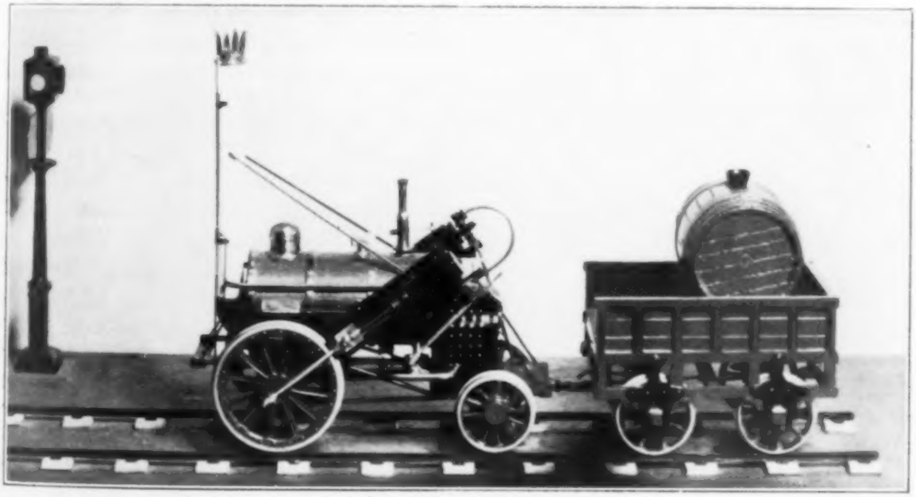
VICTOR K. LAMER

STATISTICAL CHARTS REGARDING EMPLOYMENT EXHIBITED AT THE NEW YORK MUSEUM OF SCIENCE AND INDUSTRY

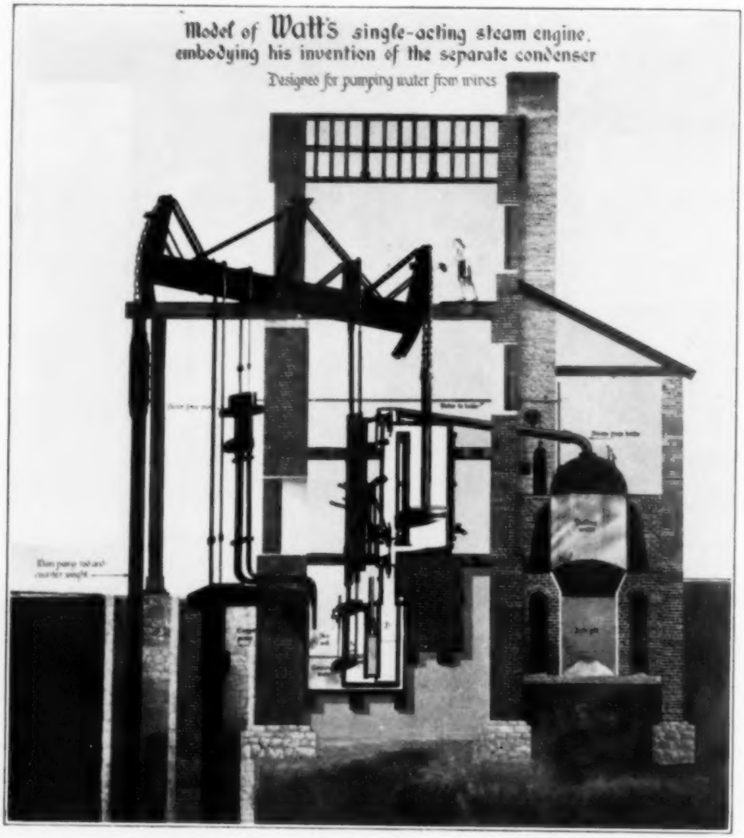
ANY approach to a statistical study of the relation of science and inventions to employment should from the start recognize two aspects of the situation—one, the influence of those scientific discoveries and practical inventions that have created new industries or new services, and the other, those inventions that have

SPINNING WITH A BOBBIN AND WITH A HIGH WHEEL
THESE TWO FIGURES ILLUSTRATE THE FIRST METHODS OF INTERMITTENT SPINNING WHICH FOUND ITS CULMINATION IN THE POWER-DRIVEN SPINNING MULE.

improved or expedited processes of production. The first have created the modern age and given employment to untold millions of workers. In some cases the increases in employment can be plotted. The second may or may not result in reduction of the number of workers employed. In certain cases resultant reduction of workers can be plotted, but the secondary effects of such improvements in machines and methods, while they may be of greater social significance



THE "ROCKET"
THIS LOCOMOTIVE, BUILT BY ROBERT STEPHENSON & COMPANY FOR THE LIVERPOOL & MANCHESTER RAILWAY IN 1829, WAS THE FIRST TO INCORPORATE SEVERAL FUNDAMENTALS OF MODERN DESIGN: HORIZONTAL, MULTIPLE FIRE TUBE BOILER WITH WATER JACKETED FIRE BOX; USE OF EXHAUST STEAM IN SMOKE STACK TO PRODUCE FORCED DRAFT; PISTONS DIRECTLY CONNECTED TO DRIVING WHEELS BY CRANK AND CONNECTING ROD.



OPERATING MODEL SHOWING PRINCIPLES OF WATT'S CONDENSING ENGINE

THE ENGINE REPRESENTED WAS BUILT IN 1788 AND WAS DESIGNED FOR PUMPING WATER FROM MINES. THE OPERATION OF THE MUSEUM MODEL SERVES TO CONTRAST THE SEPARATE CONDENSER OF WATT WITH THE CYLINDER CONDENSATION OF THE EARLIER NEWCOMEN ENGINE MODEL AT ONE SIDE.

than the reduction in numbers employed, are difficult to set forth and to weight as to relative values.

One common effect of the introduction of labor-saving machinery is to reduce the price of the article produced or the service furnished, an effect that often reacts broadly upon large numbers of consumers. Another effect often resulting is increased efficiency in the product or service, which also results in increased consumption and constitutes an economic and social gain to consumers at large.

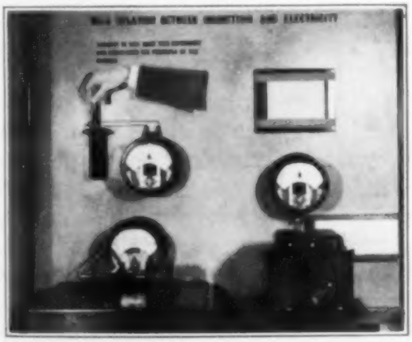
With certain comparatively recent inventions based on important scientific discoveries which have resulted in new services utilized by millions of people, such as the telephone, radio and motion pictures, convincing statistical presentations are comparatively simple, inasmuch as they have produced, either wholly or in large part, entirely new opportunities for employment. In other cases it is possible to contrast the numbers employed to-day with those engaged in the corresponding industries that have been replaced.

In still other cases difficulties of statistical presentation are far greater. With great industries and services, such as automobile production, distribution and

maintenance, steel ship-building and railroad equipment and operation, which utilize the products of many contributing industries, the problem of statistical presentation is infinitely more complex.

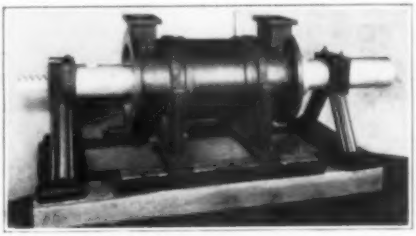
The charts developed by the New York Museum of Science and Industry relate to the following scientific discoveries and inventions: the cotton gin, the rayon process, mechanical refrigeration, the incandescent lamp, the various inventions that gave us the modern automobile, the steam locomotive, air brake and signaling apparatus—essentials in modern steam railroad development — the marine engine, propeller and steel ship fabrication — fundamental to modern shipping — the airplane, the telephone, radio, motion pictures, the discoveries of Faraday and other scientists which underlie the development of the electrical industry.

A case typical of fairly sound opportunities of comparison between the numbers employed in a replaced industry and those employed in the present situation, and also one involving the element of unknown numbers of persons employed in contributing industries, is furnished by automobile production, operation, maintenance and distribution. This case was presented as follows:



DEMONSTRATION OF THE FARADAY EXPERIMENT

THIS EXHIBIT BRINGS OUT THE MEANING OF FARADAY'S CLASSICAL EXPERIMENT AS THE BASIS FOR THE DEVELOPMENT OF THE ELECTRICAL GENERATOR.



WILKINSON'S BORING MILL

A REPRODUCTION OF JOHN WILKINSON'S BORING MILL. THE ORIGINAL WAS BUILT ABOUT 1775 AND MADE POSSIBLE THE CONSTRUCTION OF WATT'S STEAM ENGINE BY PROVIDING A MEANS FOR BORING THE STEAM CYLINDERS.

Science and Inventions that Create New Industries and New Services Make More Jobs

Automobile Industry

The inventions that have made the automobile possible were responsible for the direct employment in production, distribution and operation of 2,409,394 persons in 1930, without counting those employed in contributing industries such as steel, rubber, glass and textiles. These figures may be compared with the number (976,004) engaged in the production of horse-drawn vehicles and in their operation and care in 1900.

Similar to the case of the automobile industry is that of the railroads, which employed 1,798,171 persons in 1930 in manufacture, including air brakes and signals, construction, administration, operation and maintenance, as compared to 68,173 persons employed in 1850 in the carriage and wagon industry, including drivers, livery stable keepers, saddle and harness makers, drivers and teamsters. This figure, when corrected to correspond to the increased population in 1930, becomes 360,307.

Somewhat similar conditions are presented by steel ship-building, which is largely an assembling industry. Because of this fact it is very difficult to make comparisons with employment in the days of wooden ships.

CARRIAGE AND WAGON INDUSTRY, 1900*

	No. persons employed
In carriage and wagon factories	73,812
In harness and saddle factories	40,193
Carriage drivers, teamsters, draymen	541,115
Livery stable managers and assistants	36,918
Hostlers and stable hands	65,381
Blacksmiths	218,585
	976,004†
† This figure, corrected to correspond to the increased population in 1930, gives	1,572,928

AUTOMOBILE INDUSTRY, 1930*

	No. persons employed
In motor vehicle factories	253,228
In body and part factories	241,813
In tire and tube factories	96,249
Chauffeurs and drivers	972,418
In filling stations	150,521
In garages, repair and parking	120,129
In truck, transfer and cab companies	82,045
Bus conductors	1,002
Dealers, wholesale and retail	491,989
	2,409,394

* U. S. Census, 1900, 1930—Report for Occupations.

In only one instance, the manufacture of incandescent lamps, was it found possible in the time available for the development of the museum's legends to present statistically what have been referred to above as the secondary effects of inventions aiming at improvements in production processes and the reduction of labor.

Incandescent Lamps

The history of incandescent lamp production shows strikingly that statistics of employment do not reveal all the social implications of an industry. In 1920 about 26,000 persons were employed in the production, development and wholesale distribution of incandescent lamps. At that time approximately 322,000,000 lamps were produced and the average price was 34 cents. For the next ten years continuous improvements in methods of manufacture increased the efficiency of the lamp and reduced the number of employes to 15,000 by 1930, but because of the experience so gained, another industry—the manufacture of vacuum tubes—was developed in the same plants, which brought employment to 10,300 persons. In 1930 there were 574,000,000 lamps produced, which sold for an average price of 14.2 cents. This lower cost to the consumer, together with increased efficiency of the lamp and decreased cost of current supplied from central stations, reduced the cost of illumination to the consumer from $6.90 per 1,000,000 lumen-hours in 1920 to $3.50 in 1930.

The result of a number of other inventions, such as those relating to spinning, weaving and knitting, which are responsible for great modern industries, have not been presented because of inability to compare the numbers engaged prior to the fundamental inventions which made the application of power possible in these industries with those employed to-day.

The museum traces in its exhibits the great inventions that have brought mechanical power to the aid of industry. These inventions are, of course, those of super-importance in this matter of employment. Mechanical power produced the industrial revolution and in so doing, produced the modern world. To trace the number of persons employed to-day because of the invention of the steam engine would be practically to compare the number of wage-earners in present-day Western Europe and the United States with the unknown number of wage-earners in these regions before the inventions of Watt in the late eighteenth century.

CHARLES R. RICHARDS